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Cover illustration: Thin sections of several different habits of barite. Photographs: Jane Clarke.

Botryoidal barite Mag 538; ppl.	Acicular barite Mag 549; xpl.	Poikilotopic barite Mag 530; xpl.
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The Geoff Brown Memorial Lecture: Deccan Traps and Dinosaurs

Dr Mike Widdowson, Open University

Introduction

The Deccan Traps, continental flood basalt province (CFBP), are in the forefront of scientific research, especially the geo-sciences, and I would like to explode some of the myths which surround the Deccan Traps regarding environmental crises and the K/T boundary. I entitled this talk Deccan Traps and Dinosaurs but that is only a small part of the much more complex story of what went on 65Ma ago on the island India as it migrated across the Tethys Ocean, crossing over the Reunion hotspot plume to produce the vast piles of lavas which make up the Deccan Traps.

CFBPs are often portrayed as "flat layers of boring basalt". They are anything but boring and if you look at individual lava flows in Antrim or Skye, you will see that, far from being horizontal layer cake stratigraphy, there is a whole range of interesting, almost 'sedimentary type' structures, for instance: offlap onlap, erosion, together with lava flows filling in topography, lava flows that 'ride over' pre-existing topography and anastomising flows. In fact there is a whole complex of geometries within these stacks of lavas which we are only just beginning to tease apart (Figure 1).

Figure 1. View of the Deccan Traps lava succession near Mahabaleshwar (c. 18ºN). This part of the succession consists of lavas and flow fields that comprise the Poladpur-Ambenali-Mahabaleshwar Formations (see Table 1).

Deccan Traps (Figure 2) is one of the large igneous provinces (LIPs), (sometimes referred to as continential flood basalts (CFBs or CFBPs)) such as Karoo, Paranar, Central Atlantic Magmatic Province (CAMP) which is related to the rifting of the Atlantic, North Atlantic Igneous Province (NAIP) of which Skye is part, Ethiopia, Columbia River which has been investigated in detail by Steve Self, and the Siberian Traps. There has been a lot written about the ages of these eruptions and a number of authors have noted that they appear to coincide with extinctions. However, this extinction coincidence depends how good the dating is, and a dating error of a few million years, whilst it might not seem particularly large in the range of geological time, makes all the difference when dealing with extinctions.

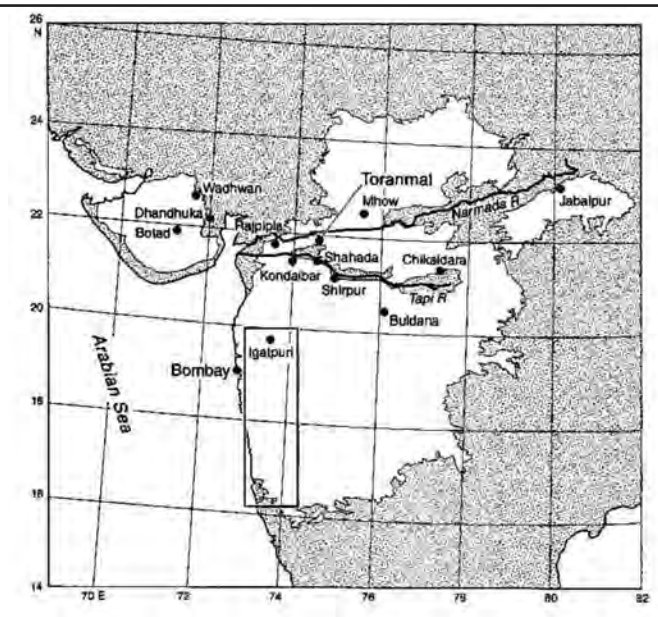


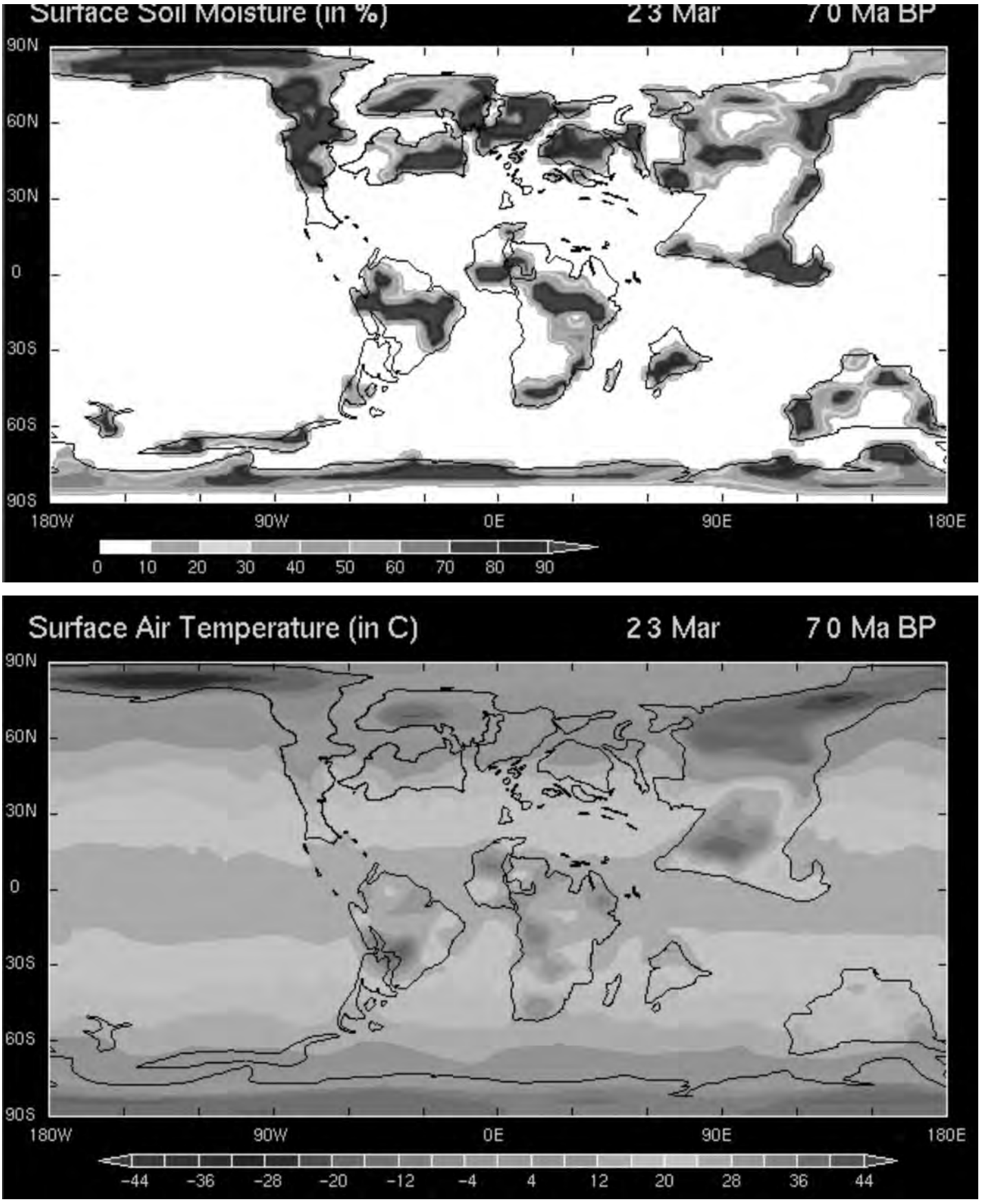
Figure 2. Map of the extent of the Deccan Traps lavas. The box delineates the well-studied area of the south-western Deccan where the chemostratigraphy (Table 1) was first established.

Characteristics of CFBPs and the Deccan Traps

When flood basalts erupt fundamental changes in topographic configuration occur especially at the meso- and macro-scale. As India moved northward over the Reunion hotspot at about 15cms per annum the lavas that were erupted built up on the subcontinent to cover almost a quarter of India which at this time was an island. It should be noted that CFBPs are often the result of both a mantle plume and associated continental rifting. In these instances the continents begin to pull apart and the edges of continents began to warp as they are rifted. This is important for a number of reasons, one of the most important of which is that it fundamentally alters the drainage pattern of the continent.

Table 1. Nomenclature and approximate maximum thickness of the major stratigraphical units of the Deccan CFBP. Packages of flows with similar chemical and isotopic characteristics comprise the different subgroups and formations.

Group	Subgroup	Formation	Thickness (m)
Topmost lavas			
	WAI	Panhala	>175
		Mahabaleshwar	280
		Ambenali	500
		Poladpur	400
DECCAN	LONAVALA	Bushe	325
BASALTS		Khandala	100-180
		Bhimashankar	>140
		Thakurvadi	650
	KALSUBAI	Neral	80-145
		Igatpuri	>150
		Jawhar	>700
Lowermost lavas			



Figures 3a and 3b. Global soil moisture (3a) and surface temperature (3b) model for the Late Cretaceous (Maastrictian) 70 Ma. The date indicated corresponds to the autumn equinox for the southern hemisphere. The model reveals that a hot, high-moisture, climate existed in India at this time. These subtropical climates are likely to have further intensified as India drifted further northward toward the equator, and represent the type of climatic conditions into which the Deccan lavas were erupted (67 – 64 Ma). Heavy rainfall, and high temperatures explain why many of the individual flows, and associated flow field surfaces, became highly weathered prior to being covered by subsequent lava eruptions. Such weathered horizons are commonly preserved as 'red boles' in the lava's succession. (Reproduced with permission of Bob Spicer)

An advanced climate palaeo model, produced by Bob Spicer, Paul Valdez and others, (Figures 3a & 3b) may be used to show the coupling of the ocean and the atmosphere and reveal information about temperatures, rainfall and soil moisture in the past. 70Ma ago the summer was in January and December, because at this time it was located 30°S inside India. Most of this time the model shows temperatures between 28-36°C, but in the southern winter it dropped to 8-10°C; in other words there was a nice warm, sub-tropical climate. This is the environment into which the huge masses of basalt were extruded.

A moisture map is also needed because temperature is only half the story. For instance, was there enough water to grow anything? If plants grew then animals could feed and a complex ecosystem could have developed. It appears that most of the time it was wet; very similar to the climate experienced by Hawaii today. Importantly, Hawaii is one of the few modern analogues we have for understanding the effects before and after the eruption of a series of basalt lava flows in terms of re-colonisation of organisms and the impact of the lava eruption on the environment.

Let us now examine what is understood by the term continental flood basalt province (CFBP) with reference to observations of the Deccan geology. A given stack of lavas within the Deccan consists of single eruptions which yield huge magma volumes of up to 1000km^3 in one eruptive event. These eruptive events do not occur as single lava flows, but as a whole series of flow toes which prograde out and inflate from the inside forming a complex, anastomising pattern of flows, flow fronts and channels (Self *et al.* 1997). These lava flows can inflate to immense thicknesses, not just a few metres but commonly to tens of metres in the Deccan, and in some instances up to hundreds of metres thick such as those examples from the CRB. Eventually, a whole series of individual flows will build into a flow field, and it is the flow field that is the individual eruption event. Finally, a whole series of flow fields will build up into a flood basalt province. It is interesting to note that many of these flow fields are dominated by pahoehoe flows similar to those in Iceland or Hawai. These are ropey structures, with crinkly tops, which grow from a single point. Field examples revealed in field exposures show a whole series of core-like structures indicating that lava toes vented from point sources and then inflated. Many examples have crusts on the outside which define where inidividual lobes sit on previous lobes.

To understand the stratigraphy we have to tease this complex series of lava toes, flows and fields apart. Often an individual flow can be traced in the field for a few kilometres but after that it breaks down as the flow may be entering another toe. One method is to look at the chemical composition of the different lava flow fields and divide them up as packages; but why does this chemical approach work? Upwelling hot magma generated within the mantle produces the basalt melt which ponds at the base of the crust. Whilst it is there it heats the overlying lithospheric lid, partially melts it, and so becomes contaminated. Consequently, the original 'picritic' melt that was generated in the upper mantle begins to acquire elements such as Be, Sr, Rb and Pb from the continental crust. As lava dykes from the ponded magma ascend through the continental crust, more contamination occurs. The chance of producing exactly the same signature of contamination between two different upwelling magmas is almost nil; each one is unique in its finger-print, so there is a change in chemical composition over time, and this changing composition gives the basis for a stratigraphy (Table 1). Consequently, the entire Deccan succession can be divided into a series of different chemostratigraphic units. This approach represents the summation of a quarter of a century of work by different teams. Having established the stratigraphy the timing and duration of different eruptive units can be estimated, which is absolutely crucial when determining any affect on the environment (Mitchell & Widdowson 1991, Widdowson *et al.* 2000).

An overview of CFBP research, eruptions, meteorites and the Cretaceous/ Tertiary Boundary (KTB)

A brief history of CFB research with respect to the Deccan details the way in which earth scientists have dealt with CFBPs and their effects and how the important issues have evolved within the Geosciences over the last 20 years. In the 1980s petrogenetesists and hard rock geologists were primarily interested in determining how basalt lavas were generated, and the associated changes in chemistry. However, interest then moved to the dating of the lavas. This was largely achieved using the K-Ar method with which estimates of ±10Ma were acceptable since these determined where the CFBPs could be placed in the geological column. The next stage of research was to look at how the magma was produced in such massive volumes over apparently short periods of time.

It is believed that basalt is generated due to plumes from the core-mantle boundary raising the temperature as they reach the upper mantle. If the plume rises under a continent that continent might become thermally weakened because there is a hot mass underneath. Such weakening can lead to rifting and as the rift pulls apart it thins and stretches and enables the mantle to rise further producing a decompressive melt which produces the massive amounts of magma so typical of the flood basalts. Such massive, short term eruptions must surely have had a devasting effect upon regional or global environments.

However, in the early 1980s two scientists, the father and son Louis and Walter Alvarez, made the apparently outrageous speculation that if a meteorite hit the earth there would be devastation, extinction due to global wildfires and dust in the atmosphere creating conditions similar to a nuclear winter (Alvarez *et al*. 1980). They also suggested that such impacts may explain why we observe extinctions in the geological record. This speculated scenario was given scientific credence with the discovery of irridium anomalies and the finding of the Chixulub impact in the Gulf of Mexico. Concurrently Dewey McLean, a palaeontologist, was investigating how flood basalts might affect the environment, and asserted that it was not accidental that the Deccan flood basalt coincided with the K/T boundary (McLean 1985). Subsequently, a paper published by a French team (Courtillot *et al.* 1988) which took all the data which had ever been recorded from the Deccan and integrated them with palaeo-magnetic data came to the conclusion that the Deccan eruption had lasted a maximum of one and more probably only half a million years. This paper re-ignited the debate because this massive eruption appeared to have occurred extremely rapidly at the K/T boundary.

At this stage a number of people began to suggest that other flood basalts must have had an environmental effect (Rampino & Self 1984). Volcanologists like Steve Self began investigating sulphur

production by CFBPs because sulphur dioxide is a very common gas in basalt eruptions and, importantly, it has a detrimental effect on the climate because if it gets into the stratosphere it has a cooling effect. However, if it does not enter the stratosphere it is simply rained out as indicated by measurements taken of the modern eruptions of Pinatubo, Mount St Helens and others.

To summarise, the scientific debate suggests there are two potentially environmentally devasting events at the K/T boundary: the Chixulub hitting the Gulf of Mexico, whilst on the opposite side of the globe the Deccan was erupting high sulphur content basalt very rapidly. How could the Late Cretaceous environment survive?

In order to determine the relative effects of these two events it is necessary to investigate further the timing and duration of the Deccan Traps eruptions, and the nature of the K/T impact boundary.

The K/T boundary is not a simple boundary. There is the irridium boundary layer but within the clay above this layer there is in one of the classic N American sections, a coarsening upwards sequence followed by a fining upwards lake sequence. Bob Spicer has worked in this area and found evidence of a water fern in the lake deposit which lies on top of the boundary layer clay. Clearly sunlight was available enabling plants to grow immediately after the impact. However, this particular fern never completes its life cycle for quite a number of years after the impact and so it seems that the temperature had cooled preventing it completing its full life cycle. Such evidence suggests that perhaps it was the meteorite impact that had the major effect upon ecosystems.

If we now consider the Late Cretaceous environment in India, we know that the climate was conducive to life, we know we have enough water, but was there anything living? Recent investigations (Widdowson & Spicer unpublished data) demonstrate that there were a whole series of contemporaneous lakes developed round the edge of the lava field during the lifetime of the volcanic Deccan eruptions, whereas towards the centre where there were thicker and more frequently erupted lava fields, "a lava desert" existed.

Clearly the dating of the Deccan and its relationship to the K/T boundary, was crucial to determining whether the lava eruptions had also had a significant effect upon Late Cretaceous ecosystems. I did not agree with the 'short duration' world of Courtillot *et al.* (1988) because I had investigated how the volcanic edifice had evolved over time, how it had grown and how it had built up (Mitchell & Widdowson 1991). Bearing in mind the rate at which the continent had moved over the plume hotspot and how the lava flows had stacked up with respect to this movement, I felt that the observed lava pile structure could not have been produced in only half a million years (Mitchell & Widdowson 1991). In other words the continent would not have moved far enough to produce the different eruptive centres I was observing (Figure 4).

Thus, there were two scenarios for the duration of the Deccan: an argument based on argon dates which were the best obtainable at the time, and a structural, or volcanic, argument which indicated a longer eruption period. To resolve this riddle there were a number of questions that needed solving: first we had to determine the eruption duration accurately and its timing with respect to the KTB and this is work that has been conducted at the OU with

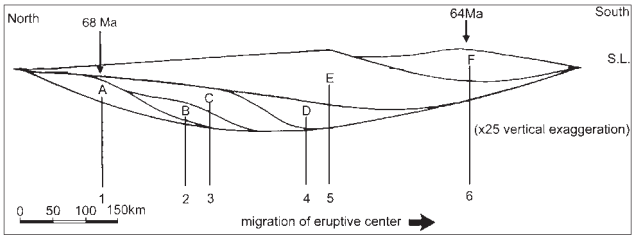


Figure 4. Schematic north-south cross section along the western margin of the Deccan CFBP showing how the macro structure of the province developed with time. The earliest lavas (c. 67 Ma) were erupted in the north generating an early volcanic edifice (A), and successive eruptive phases built on the southern flanks of earlier edifices (B C D E and F) as India moved northward over a stationary mantle plume. The final eruptions occurred in the southernmost region (c. 64 Ma).

great success over the last few years; second, we need to determine whether there is a variation in lava volume production over time. To do the latter it is necessary to get in between the flow fields and work out when each erupted, what the volumes were and how long they took to erupt. This work is currently ongoing at the OU and it has become clear that it is most important to determine the timing of the major flows; because, if there are some particularly large flows which make up huge lava fields, then such eruptive events could perhaps cause the anticipated damage. We also need to derive better estimates of SO_2 and CO_2 production during CFBP events and need to determine more accurately the style of eruption. Commonly, basalt eruptions are considered quiescent because they de-gas as they come to the surface, and only in rare instances do they produce fire fountains. If this style of eruption is the case then it is very difficult to produce ash, more crucially, it is also very difficult to blast the gases into the high atmosphere where they are going to cause the damage and thereby have an effect on climate.

With respect to duration of individual eruption events studies based on the Roza flow field of the Columbia River Basalt (CRB) province of Washington State, N America, 1300km^3, gives an estimation of 15-50 years to construct, inflate and build out pahoehoe toes and then inflate (Self *et al*. 1997). So the Roza field occurred over decades, not something that happened overnight.

The Laki eruption of Iceland is, perhaps, the most famous analogue of flood basalt eruption. At Laki there are the cones which fed the lava flows in 1783-84 but they produced only 15km^3 compared with 1400km^3 which are typocal of the Deccan and CRB. The Laki eruptions lasted about eight months but the same volconological processes were operating, such as fire fountains and eruption columns. However, it is known that the heat generated from the lava field and from the fire fountains was enough to cause local atmospheric convection and take the gases and the ashes up into the stratosphere. So, although Laki's 15km^3 was 2 magnitudes smaller than a typical CFBP eruption event it had profound effects on local and regional environments throughout the northern hemisphere. For instance, a dry sulphurous fog was carried over Europe and Eurasia by low pressure systems which took the gases and the ashes south-eastwards from Iceland. Within a couple of weeks this dry acidic fog had moved across Europe, and in Iceland up to 25% of the population died along with most of the

livestock. In addition there was crop failure and famine in Ireland, Scotland, France and Switzerland. Initially the weather became ominously warm because the gas was trapping the heat in the lower parts of the atmosphere, during these very dry and arid conditions crops withered. However, once the sulphur reached the stratosphere (12-13km high), there was a cooling effect which lasted for two winters resulting in the lowest temperatures ever recorded in north-east USA; the Mississippi froze at New Orleans and there were icebergs in the Gulf of Mexico. All of this was a consequence of a 14km^3 eruption. If Laki is an appropriate CFBP analogue then the big flood basalt eruptions of Columbia River or Deccan, which are up to 1400km^3 in a single eruptive event, must have had a somewhat greater effect.

Reconstructing the environment on the CFBP lava fields

How does the vegetation in Hawaii respond to repeated lava eruptions? After a few months little ferns begin to grow in the cracks formed by cooling fractures. Once organic life starts, its subsequent decomposition products breaks down into humus and provides a soil on which grasses can colonise. After five years or so little shrubs begin to establish themselves. Kioukas (where a lava flow goes around an existing topographic high and preserves it as an island of vegetation) are another means of preserving a complex ecosystem during and after eruptions; these islands act as seed beds from which flora can re-establish itself upon the surrounding volcanic desert and re-colonise the area. For instance, after Mount St Helens erupted there was very rapid re-colonisation through a number of means. Streams cut down through the smothering ash and fern spores, triggered by warmth and moisture, started to grow. Also blocky masses of original soil containing seeds and rhizomes that had been rafted down by volcanically generated mass flows after the main eruption, settled and began to grow. These modern analogues provide a useful insight as to how the ancient environment of Late Cretaceous India may have responded to the repeated lava eruptions.

Recent detailed investigation of the soils and sediments preserved between the successive lava flows at the Deccan, reveals a complex mosaic of different environments. For example, wide spaced occurrences of limestones and cherts in the southern and eastern Deccan Traps, indicate the presence of many shallow lakes with established ecosystems. Some of these lakes were quite large and existed around the periphery of the Deccan lava fields and were contemporaneous with the Deccan eruptions. Elsewhere, infra-trappean sections reveal soil horizons with well-defined contacts above and below. These were probably ash deposits which were laid down on the lava field by more explosive eruptions. Such explosive eruptions could have been the mechanism by which quantities of the volcanic gases entered the stratosphere. Within these cooked ash-derived soils are the remnants of vegetation, including pollens and spores of the plants which were colonising the soil. Flora preserved in the lake deposits include cycads, gymnosperms such as *Araucaria* (a variety of the modern monkey puzzle) and horsetails. The fauna was similarly diverse with crocodiles, turtles, fish and even dinosaurs; in effect there was a complex ecosystem living alongside the ongoing massive eruptions.

Dinosaur nests have been reported from a number of sites around the Deccan, typically presented in terrestrial sands or caliche-limestones. Clutches of dinosaur eggs were laid in small sandy hollows on top of the lava flows at the periphery of the Deccan. The position of these can be determined within the lava stratigraphy because of the geochemical analysis. The examples occur nearer the top of the succession than the bottom, which means that a considerable amount of the Deccan had erupted whilst these types of animals were still living round the periphery of the lava fields. Until recently it was not accepted that dinosaurs lived during the eruptive phase. The problem was that in many instances where Deccan dinosaur nests were found they appeared to lie below the lava flows. A whole area in Indian geological literature is divided into 'infra-trappeans' which is material that lies below the traps, and 'inter-trappeans' which is material preserved in between the traps. Detailed and careful mapping indicates that these are one and the same because a potential infra-trap is often contemporaneous with a potential inter-trap and the one passes laterally into the other. Some dinosaur remains are bracketed on either side by lava flows so their position in the lava succession can be established precisely. Such infra and inter-trappean materials provide a valuable insight into the environments that existed during the Deccan eruptive episode and the degree of re-establishment of successive ecosystems. Our preliminary assessment of the deposits is that they do not indicate an environmental disaster caused by the poisoning of the soils and atmnosphere by volcanic gases. Instead, they suggest that flora and fauna was robust enough to resist any long-term detrimental effects, and was able to re-establish around the periphery of the lava fields despite the massive outporings of magma and gases that were occurring toward the centre of the Deccan volcanic edifice some few hundred kilometres to the west.

At Rajamundry, on the eastern coast of peninsular India, a series of quarries have exposed an ash layer covered with lava flows; beneath these there are also some well-presented shallow marine sediments. Marine conditions are a good barometer of environment and these examples contain normal Tethyan margin gastropods and bivalves. In fact there are particularly large gastropods which clearly had a lot to eat, not tiny impoverished individuals which might be indicative of a contemporaneous volcanagenic environmental disaster. Dating the lavas indicates these organisms were living happily in warm coastal waters, at least 2Ma after the onset of the volcanism.

Timing and duration of the Deccan Traps eruptions

As indicated earlier the nature of the broad volcanic configuration of the Deccan Traps lava pile reveals that it is most unlikely that the entire succession was erupted in only 0.5-1.0Ma. This arises because as the continent moves over the hot spot, the first eruption occurred in the most northerly part of the province (at *c.*22-23°N). As the continent continued to move further north, so the next eruption occured to the south of the last one as were all subsequent eruptions. In effect later lava eruptions always built onto the southern flank of the earlier eruptions except if there was a particularly large eruption which then might have smothered a large proportion of the original volcanic construct (Figure 4). However, in order to get the observed stratigraphical geometry, given the rates of continental movement of India (*c.*15cmyr^{-1}) the Deccan edifice cannot have been constructed in less than 5Ma. Since the OU has one of the best argon-argon (^{40}Ar/^{39}Ar) dating labs in the UK I decided to test this hypothesis: was it half a million years as suggested by previous researchers or was it nearer 5Ma as I believed?

We have now dated the lavas from the north to the south of the Deccan province and found that the oldest lava flows were 67Ma and the youngest ones were 64Ma. Moreover, given that the KTB occurs at 65.4Ma it can be seen that the Deccan eruptions actually started substantially before the K/T boundary and continued for some conciderable time after the K/T boundary over a duration of 3-4Ma. But these precise dates only present one aspect of the story, the other important question concerns the volumes of lava which were produced per unit time. For instance, did they vary with time and did the individual eruptive events have such a magnitude that they fundamentally affected conditions? The answer to the latter seems to be "no" because it has been demonstrated earlier that the flora and fauna lived contemporaneously for a considerable amount of that eruptive history.

Both the areal extent and thickness of the Deccan Traps is known and, taking into account post-eruptive crushing, the original volume is estimated to be about 750,000kms^3. We also now know that the Deccan volcanic ediface grew over 4Ma. If we make the assumption that half of that volume was erupted in only half a million years, it becomes possible to estimate the annual lava production rate. Moreover, we know roughly how much sulphur is in each unit mass of basalt so we can work out the mass of sulphate aerosols that were produced. Since the climate today is related directly to the production of volcanic SO_2 we can determine roughly what the cooling would be if those sulphate aerosols entered the stratosphere. Given an annual preduction rate of 0.75km^3, and that for every kilogram of basalt erupted 0.001kg of sulphur was liberated to the atmosphere, this would generate 5.5x10^{9}kg of sulphate aerosols. From modern analogues this amount of sulphate aerosols would produce a climate forcing of only -0.8Wm^{-2}yr^{-1}. That is half as much as El Cuchon and would not be noticable. However, this is a spurious argument because it is a time-averaged estimate, and we know that eruptions do not happen in this fashion; they do not conveniently time-average themselves over half a million years.

If we repeat the calculations using more realistic estimates we find that we are approaching the point where the climate is fundamentally affecting the weather from one single event. For instance, the larger single Deccan eruptive units are probably of the order of 750km^3, and were erupted over periods of decades. If such an eruption event were emplaced over 50 years, the annual climate forcing would be -16Wm^{-2}yr^{-1}, whilst if it were erupted over only 10 years the climate forcing would be -80Wm^{-2}yr^{-1}. Interestingly, the former estimate approaches the effect created by the 1815 Tambora eruption (-21.4Wm^{-2}) which caused a 1°C cooling in the northern hemisphere, whereas the latter is four times greater than this effect. Moreover, such climate forcing would have appeared over decades, rather than as a single event. Under such circumstances the effect on the Deccan region, and global climate as a whole, may have been profound.

So it is not the timing or the duration of the province as a whole that is the real issue, it is how eruptions occur: the volcanic plumbing and style of eruption. The calculations indicate that if there are small eruptions over a long period of time they may not have an effect, that seems to be borne out by evidence from the flora and fauna, but there were perhaps a small number of such as 750km^3 eruptive units, then these really big eruptions could have caused the damage. So, in principle, the damage could have been caused by just a few units within the Deccan.

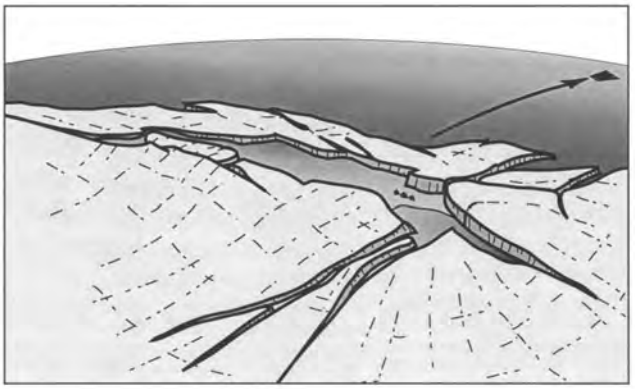


Figure 5. Schematic overview of the rifting along the continental margin of western India (c. 66 – 62Ma) during which the Seychelles microcontinent broke away from greater India (view is looking southwestward along the rifting margin). The low-lying gulf between the separating landmasses provided a route along which shallow marine conditions became established, leading to water-magma interaction and highly explosive volcanism in the Bombay area.

Finally it is worth noting that there was a different style of eruption at Bombay where the lavas erupted into water so forming beautiful pillow lavas. Here are also evolved silicic ashes interlaced with the Bombay lava stratigraphy which indicate particularly explosive eruptions. It is interesting to speculate whether these explosive eruptions may have been the cause of the damage to the ecosystems at the K/T boundary. However, dating of these ashes yields a 62-64Ma age so they clearly occurred after the event. Nevertheless, these were very large and important eruptions. Why did they occur at that particular stage?

Consider a Cretaceous overview of north-eastern India at *c.*65Ma (Figure 5) when the continental crust which now forms the Seychelles rifted away from western India. This rifting was part of the mechanism which caused the decompression of the mantle plume beneath and which produced vast amounts of lava that formed the Deccan CFBP. As this rifting occured a nascent ocean was formed in the gulf along the rift axis and as that water encroached it changed the style of eruption from one of relatively quiescent sub-aerial basalt effusion, to phreato-magmatic where water interacted with the hot, rising magma. This would have produced a much more energetic style of eruption which we see preserved in the ashes and as pillow lavas.

Conclusions

In summary: what have we learnt about the Deccan CFBP, its style of eruption and its environmental effects? First of all there is evidence of re-colonisation, a re-establishment of ecosystems in and around the Deccan during the eruptive phase. How can this be reconciled with the volcanism? If damage was caused and the dinosaurs died out through some kind of volcanic effect, then the damage may have been done by relatively few huge eruptions. Nevertheless, some degree of explosive volcanism would have been required for the aerosols and ashes to be injected into the stratosphere. In some instances there is evidence that this might

have occurred because ash is preserved between lava flows. In effect it seems that long-term permanent environmental damage could only have been achieved if there were sustained eruptive phases during which large volume eruptive units were produced. A series of such eruptions in a relatively short period of time may have been sufficient to damage local, regional and possibly global ecosystems beyond recovery leading to a positive feedback scenario and eventual ecosystem collapse.

The challenge now is to explore whether such large eruptions within a CFBP succession like the Deccan do have the potential for widespread ecological damage, to identify where they occur, and to determine their timing relative to the KTB. Only this type of approach will aid in discriminating between the effects of volcanism and those resulting from meteorite impacts such as Chixulub.

References

Alvarez L, Alvarez W, Asaro F & Michel H. 1980, Extraterrestrial cause for the Cretaceous-tertiary mass extinction. *Science* **208,** 1095-1108.

Courtillot V, Feraud G, Maluski H, Vandamme D, Moreau M G & Besse J, 1988, Deccan flood basalts and the Cretaceous-Tertiary boundary. *Nature* **333**, 843-846.

McLean D M, 1985, Deccan Traps mantle degassing in the terminal Cretaceous marine extinctions: *Cretaceous Research* **6**, 235-259.

Mitchell C & Widdowson M, 1991, A Geological Map of the Southern Deccan Traps, India. *Journal of the Geological Society of London* **148**, 495-505.

Rampino M R & Self S, 1984, Sulphur-rich volcanic eruptions and stratospheric aerosols. *Nature* **310**, 677-679.

Self S, Thordarson T & Keszthelyi L, 1997, Emplacement of Continental Flood Basalt Lava Flows. In *AGU Geophysical Monograph 100 'Large Igneous Provinces: Continental, Oceanic and Planetary Volcanism,* Mahoney J.J. & Coffin M (eds.), 381-410.

Widdowson M, Pringle M S & Fernandez O A, 2000, A post K/T (Early Palaeocene) age for Deccan-type dyke feeder dykes, Goa, India. *Journal of Petrology* **41(7)**, 1177 – 1194.

Book reviews

Regional Geochemistry of Wales and part of west-central England: stream water by M G Hutchins & B G Rawlings, BGS, 1999. £75 (hardback) (£120 with companion volume, also £75 separately, on soil and stream sediment) ISBN 0852723636.

This handsome and fascinating volume is the thirteenth in the series of BGS geochemical atlases, but the first to present multi-element date for stream water for any major region of the UK. The area includes on the east Merseyside to Wolverhampton and Gloucester, so it covers a very wide range of environment, permitting comparisons between almost every form of land use in Britain, and between streams flowing over Precambrian to Jurassic rocks.

The sections are first on the methodology of sample collection, chemical analysis, data and image processing, and statistics; then some excellent and quite detailed pages on the geology of the area; mineralisation and mining; and very full notes on the controls on stream-water chemistry: atmospheric, bedrock and soil, terrestrial organisms, weathering, anthropogenic influences, and so on. Various clear maps, diagrams, and photographs illustrate these sections.

There follow maps at 1: 900 000 of the geochemistry of the streams, for acidity, conductivity, 20 major and trace elements, and five anions (bicarbonate, nitrate, sulphate, chloride and fluoride); a transparent overlay at that scale is provided so that, taken with the major geological outlines on each map, the influences in each locality can be pinpointed very exactly. For most of the elements the frequency in the main rock facies of each geological period from Precambrian to Jurassic is shown in a small but clear diagram below the map.

Opposite the maps are considerable essays on each species, pointing out for example how Na and Cl get into the streams from marine aerosols falling in the extensive south and west facing coasts; how the nitrogen cycle works both in general and in the results of the application of N fertilisers, silage and liquid run-off from stored manure, so that the map to a large extent reflects land use; how Ca and Mg have high values in streams in areas of calcium and magnesium-rich bedrock such as the Carboniferous and Jurassic limestones, barium highest in areas underlain by Old Red Sandstone.

Finally in the atlas come "thematic multi-element studies" on such topics as solute saturation, temporal variability, eutrophication through phosphates and nitrates, acidification. Curiously, the direct influence of forestry is not mentioned in this section, though it is earlier pointed out in the controls on stream-water chemistry that the felling of coniferous forests, along with other perturbation of upland ecosystems, increases concentration of nutrients. The references and bibliography that conclude the volume would be almost worth the price in themselves!

Philip Clark, BSc (Hons) OU, MA (Oxon)

Geodynamics of the Lithosphere – An Introduction by Kurt Stüwe, 2002, Springer-Verlag, 449pp, £49.00 (hardback) ISBN 3540417265.

This book is an introductory text for all earth scientists interested in learning about the quantitative description of geological problems. The aim of the book is "…to introduce field geologists to the beauty and simplicity of descriptions with equations" and provides an ideal starting point for a quantitative treatment of their data. It is written for the field-oriented geologist who wants to begin learning about the quantitative description of problems.

After an initial chapter defining and describing scientific models and problems in geology, the book contains chapters covering most aspects of earth science from plate tectonics to geomorphology and the mathematical problems associated with the underlying processes. The book is well put together having a text that is straightforward to read and an adequate number of diagrams that are used to explain and illustrate problems. The knowledge gained in each chapter is reinforced by a set of problems (with answers provided in an annex). Mathematical tools, a maths refresher and symbols and units are the subject of other annexes. A further annex provides a useful selection of geodynamics-related internet addresses that were discovered during research for the book. The text is complemented by a comprehensive index and reference list, which will provide additional sources of information for those with a deeper interest in the subject.

As a non-mathematician who needs guidance on these matters, I found that Stüwe has provided much to complement that found in OU (and other) Earth Science texts. It is not merely a mass of high-level maths but a clearly explained use of maths to support field studies and enable a scientific explanation of the geological events that we observe. The mathematical tools and maths refresher provided in the annexes were particularly appreciated. If you need maths to explain your observations, this book is a useful starting point.

Mike Hermolle, BSc(Hons)NatSci (Open)

A preliminary analysis of the dynamics of a channelled lava flow on Pico Partido volcano, Lanzarote, Canary Islands.

Duncan Woodcock

Abstract

This paper summarises the results of a preliminary study of a channelled lava flow on Pico Partido volcano, Lanzarote. In a number of places along the channel the lava flow has "banked up" as it has flowed round bends in the channel. A lava flow velocity of around 8ms^{-1} has been calculated from an analysis of these "superelevation" features. Further analysis, assuming that the lava flowed as a Newtonian liquid, indicates that the lava viscosity was in the range 60 to 100Pa.s and that the flow was laminar. The flow appears to have been supercritical within the channel and may have changed abruptly to subcritical at a break in slope at the lower end of the channel. A lava flow feature at the lower end of the channel may have been produced by the lava equivalent of a hydraulic jump.

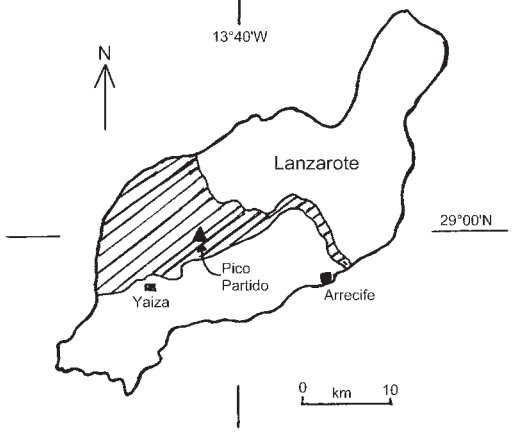


Figure 1. Map of Lanzarote showing location of Pico Partido and the area affected by the 1730-36 eruptions.

Introduction

The most significant historical eruptions on Lanzarote occurred between 1730 and 1736, when over a quarter of the island was covered with a new landscape of lava flows and volcanic cones (see Figure 1). A large part of this area is now contained within the Timanfaya National Park (Scarth & Tanguy 2001). Pico Partido is a large volcanic cone that was formed early in this eruption episode (Carracedo *et al.* 1992). The cloven profile of Pico Partido, together with the prominent channelled lava flow down its northern flank, make it one of the most distinctive volcanoes on Lanzarote. A description of the volcanic landforms around Pico Partido is given in Scarth & Tanguy (2001) and in Carracedo & Rodriguez Badiola (1991). Figure 2 is a sketch map of the area around Pico Partido.

Description of the channelled lava flow

This paper is primarily concerned with the dynamics of the channelled lava flow and its subsequent behaviour at the channel exit. Scarth & Tanguy (2001) consider that the flow was sourced by the overflow of a lava lake (the lower lava lake on Figure 2) that developed in a small vent immediately to the north of the main edifice. There is some indication that this supply of lava was augmented by eruption from the main edifice of Pico Partido, with lava flowing down the steep northern slope to accumulate in the lower lake. An additional, upper lava lake, sourced by flow east from the main edifice, may have overflowed to provide a further source of lava.

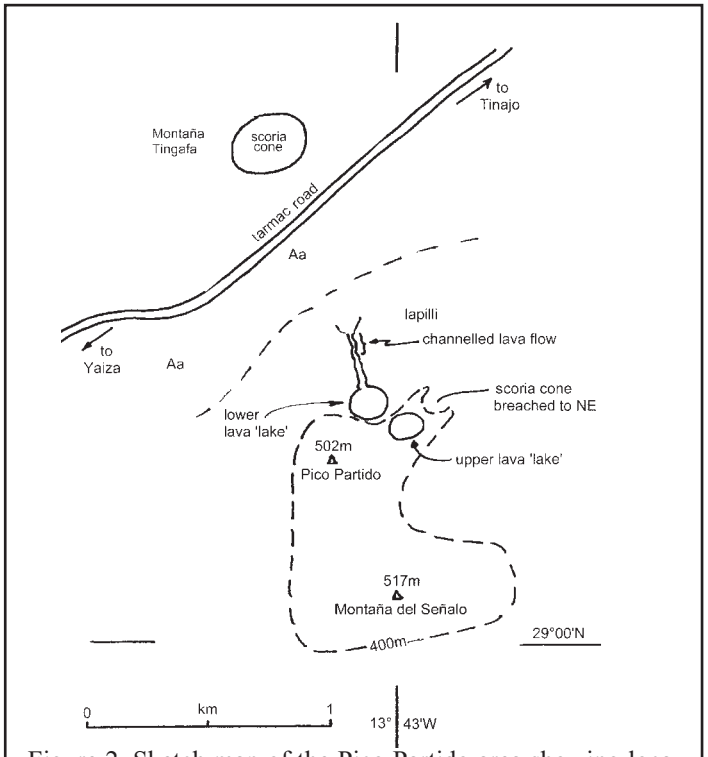


Figure 2. Sketch map of the Pico Partido area showing location of the channelled lava flow.

The most prominent feature of the lava channel is the difference in height of the lava levels on the inner and outer banks of the channel wherever the lava has flowed round a bend. In all cases the lava has "banked up " against the outside bend, as illustrated in Figure 3. This so-called "superelevation" effect provides a means whereby the velocity of the lava flow may be estimated (Heslop *et al*. 1989). Suprisingly, the superelevation in the Pico Partido channelled flow is not mentioned in Scarth & Tanguy (2001) nor in Carracedo & Rodriguez Badiola (1991); in fact the only reference to it found to date appears in a Spanish field guide (Araña 1997).

The channelled lava flow (Figure 4) is approximately 100m long. It emerges from an upstream lava tube approximately 1m high and 3m wide and flows northwards down a slope with a gradient of 1 in 5. The channel is 1 to 2m wide with walls that range in height between 2m and less than 0.5m. The floor of the channel is covered with a thin layer of lapilli scoria. The channel has six bends, of which two were examined in detail. Figure 5 shows a close up view of the outside wall of one of the bends: the wall is covered with spatter which had a tendency to run obliquely down the wall in the down-channel direction.

The location of the lower end of the channel coincides with a marked break in slope and at this point the flow widens consider-

Figure 3. View down channel showing an example of superelevation at a left hand bend. Length of hammer 280mm.

Figure 4. View west across channel from the slopes of a scoria cone immediately to the east. The superelevation at several bends along the channel is clearly visible.

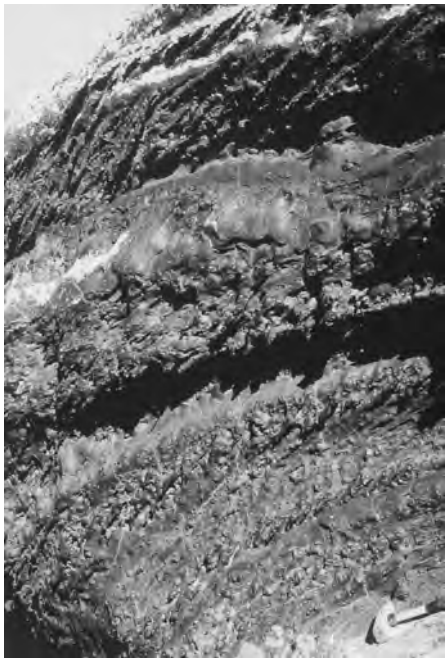


Figure 5. Details of the outside wall of the upper bend. Flow direction to the left.

ably. After a further 30m the slope steepens and the flow becomes channelled once more for a short section before roofing over and eventually running out onto an aa lava field.

Figure 6 shows the lower end of the channelled flow, where the flow bends to the right and then sharply to the left. The first bend shows the usual superelevation effect, but the subsequent bend to the left appears to be anomalous, with both walls of approximately equal height. The right hand bank comprises an elongate feature

Figure 6. Lower end of channelled flow. "Enigmatic feature" on RHS.

Figure 7. Close up view of "enigmatic feature". Length of hammer 280 mm.

that resembles the shape of a cone cut lengthways along its axis and then laid on its cut surface. Figure 7 shows a close-up view of this enigmatic feature. Later in the paper, I discuss the possibility that this feature may have been produced by the lava equivalent of a hydraulic jump.

Estimation of lava flow velocity within the channel

Superelevation in a curved channel may be related to the curvature of the channel and the flow velocity by considering the dynamic equilibrium of a mass of fluid moving at velocity v on a circular path of radius r. The centripetal acceleration required for circular motion is provided by a radial pressure gradient that is developed by the surface sloping inwards towards the axis of rotation.

By applying Newton's Second Law of Motion to a mass m of liquid on the sloping surface (see Figure 8):

$$mg \sin\theta = mv^2/r * \cos\theta$$

$$\text{i.e. } v = (gr \tan\theta)^{1/2} \qquad (1)$$

The radius of curvature of a bend was estimated in the field by measuring the orientations of successive positions of a measuring stick when laid end to end parallel to the channel walls and along the median line of the bend. The superelevation angle of a bend was estimated in the field from measurements of the maximum and minimum levels of lava and the channel width; this estimate was subsequently checked by measurements on photographs. Measurements were made at two bends where superelevation was particularly well developed. The basic data for the two bends is summarised in Table 1. The calculated flow velocities, together with the volumetric flowrates, are presented in Table 2. Figure 9

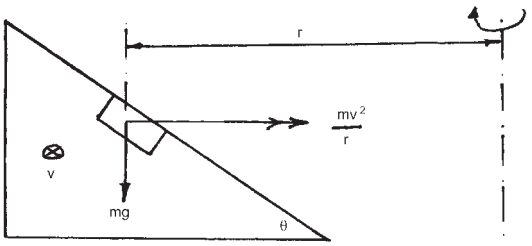


Figure 8. Dynamics of the flow of an element of liquid of mass m with velocity v round a bend of radius r.

shows a photograph used for the measurements on the upper bend, together with a sketch showing the measured parameters.

The flow velocity of around 8 ms^{-1} compares with values of 7.2 to 9.3ms^{-1} that were obtained from the superelevation features in a channelled lava flow on Kilauea (Heslop *et al.* 1989). Volumetric flowrate should be constant down the channel; the difference in the calculated values is probably due to a combination of measurement error and the limitations of the analysis leading to equation (1). The derivation of this equation is based on the assumptions that the flow is steady, that viscous effects can be neglected and that the radius of curvature is large compared to the channel width.

Heslop *et al.* consider the effect of viscosity on superelevation in an appendix to their paper (Heslop *et al.* 1989). Using the criterion they develop, it can be shown that the effect of viscosity on the development of the superelevation in the Pico Partido channelled flow can be neglected. The channel width is 1-2m, compared with a radius of curvature of around 8m, so the assumption of large radius of curvature is not satisfied. However it can be demonstrated that in our case the error introduced is less than 1% in the calculated value of the velocity.

Departures from steady flow are discussed in Heslop *et al.* (1989). The superelevation angle is determined from the highest and lowest levels of lava observed on a bend. Unsteady flow may have the effect of producing these maximum and minimum levels at different times and thus at different flowrates during unsteady flow. The error associated with unsteady flow is, unfortunately, unknown and unquantifiable. The two calculated values of volumetric flow differ by less than a factor of two; this compares favourably with a variation from 100 to 300m^3s^{-1} for the much larger lava flow studied on Kilauea (Heslop *et al.* 1989).

Table 1. Basic data for the two bends studied

	Upper bend	Lower bend
Distance of bend from top of channel / m	22	50
Radius of curvature r / m	7.2	8.4
Superelevation angle θ / degrees	40	38
Flow cross-sectional area A / m^2	0.94	1.55
Mean depth h / m	0.72	1.12
Wetted perimeter P / m	2.73	3.36
Slope of channel floor	1:5	1:5

Table 2: Variables calculated from basic data

	Upper bend	Lower bend
Velocity v / ms^{-1}	7.7	8.0
Volumetric flowrate Q / m^3s^{-1}	7.2	12.4
Hydraulic diameter D / m	1.4	1.8
D/h	1.9	1.7
Note: Volumetric flowrate Q = Av Hydraulic diameter D = 4A/P		

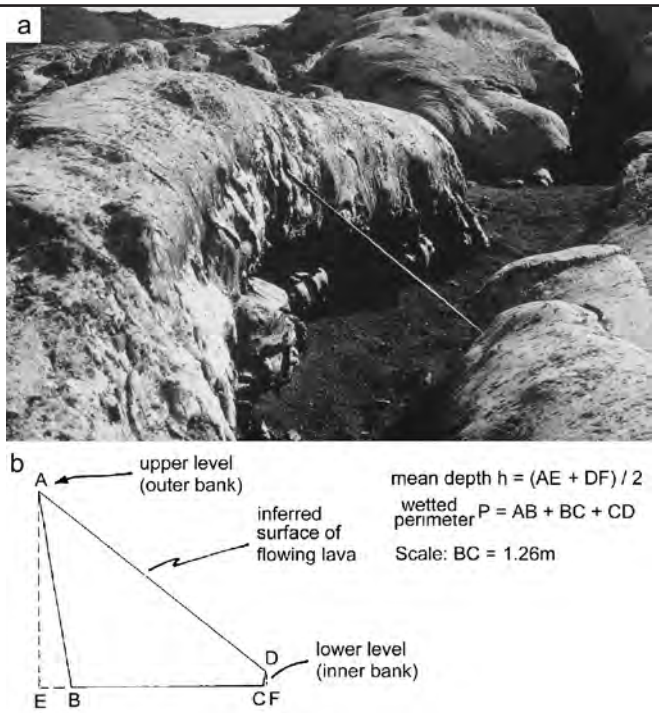


Figure 9. (a) Photograph of upper bend used to estimate channel dimensions. The lower tip of the walking stick is at the lowest point on the inside wall of the bend. Length of walking stick 1220mm. (b) Sketch of idealised channel geometry for the upper bend.

Assessment of the flow regime within the channel

A flow in an open channel is said to be supercritical if a surface wave is unable to propagate upstream. The velocity of a surface wave is given by $u = (gh)^{1/2}$, where h is the depth of the flow (Massey 1970). A flow of velocity v is thus supercritical if $v > (gh)^{1/2}$ i.e. if $v/(gh)^{1/2} > 1$, where the dimensionless group $v/(gh)^{1/2}$ is known as the Froude number, usually represented by the symbol Fr (Massey 1970).

If flow conditions change, such as at a break of slope, it is possible for a supercritical flow to be transformed abruptly into a subcritical flow. The location of the transformation is marked by a discontinuity in the surface of the flow and is known as a hydraulic jump. This situation is illustrated in Figure 10.

Hydraulic jumps will be familiar to observers of water flow in gutters and streams; furthermore a circular hydraulic jump can be observed when water flowing from a tap hits the horizontal surface of a sink. In the earth sciences, hydraulic jumps have been proposed as the mechanism for the production of "chute and pool" sedimentary structures in fluvial flow (Fralick 1999), the deposition of sand bars in turbidity currents (Weirich 1988) and in the development of lithic breccias in pyroclastic flows (Macias *et al*. 1998).

The Froude numbers for the flows in both bends studied are presented in Table 3. They have been calculated from the flow velocity and the mean flow depth.

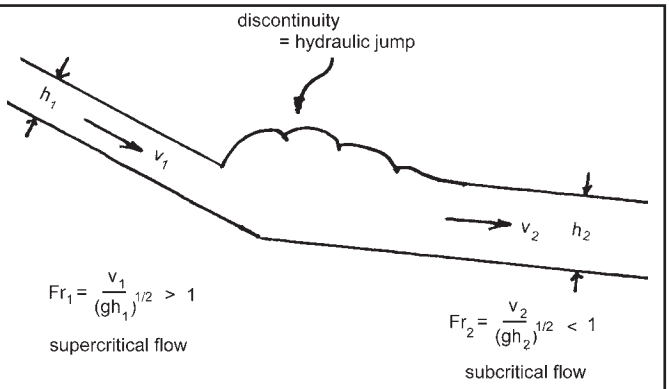


Figure 10. Development of a hydraulic jump. Supercritical flow with velocity v_1 and depth h_1 changes discontinuously to subcritical flow with velocity v_2 and depth h_2 at the change of slope.

It appears that the lava flow in the channel was supercritical, thus the possibility of a hydraulic jump exists where the flow conditions change abruptly at the break in slope at the lower end of the channel. The flow regime below the break in slope can be assessed by estimating the likely velocity and depth of flow as the lava spreads out at the channel end. In order to make this estimate, a value for the viscosity of the lava flow is required.

Estimation of lava viscosity

To estimate the viscosity of the lava flow, we need to consider the laminar flow of a viscous fluid in a sloping channel. For a channel of a given geometry, an equation can be derived for the velocity distribution in the channel by considering the balance of forces on a small element of fluid within the channel. The situation is shown diagramatically in Figure 11 for a one-dimensional case.

The gravitational body force on the fluid element is balanced by the viscous shear stresses on the surface of the element. The simplest analysis assumes that the fluid shows Newtonian behaviour, in which case the viscosity of the fluid is constant at all points in the channel. The resulting equations can be solved without difficulty for the one-dimensional cases of an infinitely wide channel or a semicircular channel. For more complex geometries, velocity varies in more than one direction and the solution of the resulting partial differential equations is more difficult. However the equations for all geometries have a similar form, being constrained by the requirements of dimensional consistency.

For a semicircular channel of radius t, the velocity at depth y is given by :

$$u(y) = \rho g \, \mathrm{Sin}\, \alpha (t^2 - y^2)/2\mu \qquad (2)$$

where ρ and μ are the lava density and viscosity .

The velocity increases from zero at the channel wall to a maximum on the surface along the centre line of the channel:

$$u_{max} = \rho g \, \mathrm{Sin}\, \alpha \, t^2 / 2\mu \qquad (3)$$

The volumetric flowrate down the channel is given by :

$$Q = \pi \rho g \, \mathrm{Sin}\, \alpha \, t^4 / 8\mu \qquad (4)$$

Thus the average velocity, $v = 2Q/\pi t^2 = u_{max}/2$ (5)

Table 3 : Calculation of Froude numbers

	Velocity v $m.s^{-1}$	Mean depth h m	Froude number	Flow regime
Upper bend	7.7	0.72	2.9	supercritical
Lower bend	8.0	1.12	2.4	supercritical

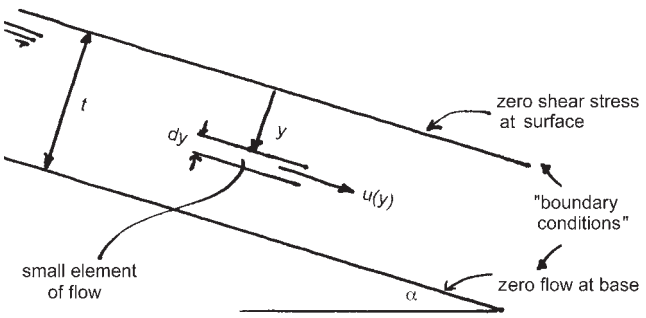


Figure 11. One-dimensional flow of a viscous liquid of depth t down a planar surface of slope α. The balance of forces on a small element of fluid at depth y can be used to obtain the vertical velocity distribution v(y).

For the preliminary analysis of the Pico Partido channelled lava flow, it is convenient to follow the lead of Heslop *et al.* (1989) and to replace the real geometry of the channel by a hydraulically equivalent semicircular channel, using the established concept of hydraulic diameter (Massey 1970). The hydraulic diameter D is defined as $D = 4^x$ cross-sectional area of flow / wetted perimeter.

For a semicircular channel of width w and depth h (= w/2) the ratio of hydraulic diameter to depth (D/h) is 2. For the two bends studied, the values of D/h are 1.9 (upper) and 1.7 (lower). The departures from semicircularity can be compared with the bends studied by Heslop *et al*. (1989) which had values of D/h in the range 2.2 to 2.8.

From equations (3) and (5), the average velocity in the equivalent semicircular channel is given by:

$$v = \rho g \, \mathrm{Sin}\, \alpha \, t^2 / 4\mu \qquad (6)$$

where the depth t is equal to half the hydraulic diameter.

I assume that the average velocity is equal to the velocity calculated from the superelevation, although this assumption needs to be assessed by a more detailed analysis. The average slope of the channel at the two bends is around 1 in 5, giving a value of Sin α of 0.2. A value of 2000 $kg.m^{-3}$ is used for the lava density. Spera (2000) quotes values for the density of ungassed basalt at eruption conditions in the range 2500-2700 $kg.m^{-3}$. The surface of the lava flow was sparsely vesicular and the density of 2000 $kg.m^{-3}$ corresponds to a gas voidage of around 20%. Unfortunately it was not possible to sample the flow without causing visual damage.

Equation (6) can thus be evaluated, yielding values for the lava viscosity of 60 and 100Pa.s for the upper and lower bends respectively. This compares with values in the range 40 to 150Pa.s obtained by Heslop *et al.* (1989) using a similar methodology.

The calculated viscosity is based on the assumption of laminar flow. It is now possible to check that the flow was indeed laminar by calculating the Reynolds number for the flow. The Reynolds number for a flow is a dimensionless number that gives an indication of the degree of turbulence of the flow. Conceptually it can be considered as the ratio of the inertial forces to the viscous forces: an increase in viscosity tends to suppress turbulence and thus laminar flow is associated with low values of Reynolds number.

The Reynolds number can be calculated from the formula

$$Re = v \rho D / \mu \qquad (7)$$

For flow in open semicircular channels, the flow is laminar if the Reynolds number is less than around 2000 (Heslop *et al.* 1989).

For both the bends studied, the Reynolds number is around 300, confirming that the laminar flow analysis is appropriate.

Assessment of flow regime below the break in slope

It now remains to assess the flow regime below the break in slope. The flow widens considerably at the break in slope, thus the flow may be modelled by the laminar flow of a thin planar sheet with a width w much greater than its depth h.

For this case, the volumetric flowrate per unit width of channel (at right angles to the flow) is given by:

$$Q/w = \rho g h^3 \text{ Sin } \beta / 3\mu \qquad (8)$$

where β is the angle of the slope and the values of μ and ρ, together with the total volumetric flow Q are the same as those for the channelled flow.

The Froude number is defined as:

$$Fr = u/(gh)^{1/2} \text{ , where } u = Q/wh \qquad (9)$$

By eliminating h from equations (8) and (9), the following expression for the Froude number can be developed:

$$Fr = (\rho Q \text{ Sin } \beta / 3\mu w)^{1/2} \qquad (10)$$

where the values of all variables are known except w.

For subcritical flow we require $Fr < 1$,

i.e. the flow width $w > \rho Q \text{ Sin } \beta / 3\mu$

The gradient below the break of slope is somewhat irregular, but a reasonable estimate is 1:10.

Whence w > 8m , based on data from both bends.

The actual width of the lava flow below the break of slope is considerably greater than this critical width, so it seems possible that the enigmatic feature in Figure 7 may have been produced by the lava equivalent of a hydraulic jump.

Conclusions

The principal conclusions of this study are summarised as follows:

i) The velocity of the channelled lava flow was around $8ms^{-1}$ and the flow appears to have been supercritical.

ii) The channelled flow was laminar with a viscosity in the range 60-100 Pa.s.

iii) The flow below the break of slope was probably subcritical.

iv) The lava equivalent of a hydraulic jump may have been present at the break of the slope and may have influenced the formation of the enigmatic feature in Figure 7.

Review

The results reported here represent a preliminary study of the dynamics of the channelled lava flow on Pico Partido. Field measurements were made with the simplest of equipment while the dynamic analysis makes a number of simplifying assumptions. Nevertheless the results are sufficiently interesting to warrant further investigation.

An accurate survey of the whole channelled flow would provide data on all the bends in the channel. It would be particularly interesting to locate and study additional examples of channelled lava flows where superelevation features allow the flow velocity to be estimated and where a break in slope at the end of the channel is exposed. In the example studied by Heslop *et al.* (1989), the lower portion of the channel has been overrun by later lava flows, covering any features formed at the break of slope.

A number of theoretical aspects require further study; these include consideration of the following questions:

i) Does the velocity calculated from the superelevation correspond to the mean velocity as assumed in this analysis or to some other velocity?

ii) How is the slope of the superelevation surface modified for a liquid of high viscosity, compared with the planar surface assumed in this analysis?

iii) What is the significance of the Froude number for a viscous flow, where there are large variations in velocity within the flow?

iv) How are the conclusions modified if the simple Newtonian model for viscosity is replaced by a non-Newtonian model such as a Bingham fluid or a power-law fluid?

v) Does the shape of the "enigmatic" feature have any significance?

vi) If the 'enigmatic' feature was produced by a haydraulic jump how did it solidify *in situ*?

It may be possible to investigate a number of these topics by a combination of laboratory experiments on analogue materials and computation.

Acknowledgements

Many thanks to Andy Harris and Scott Walker who introduced me to the superb superelevation features on the lava flow on Kilauea during the OUGS NW trip to Hawaii in 2001. Thanks also to Jenny Forrest and Linda McArdell who provided me with a copy of the now unobtainable 1:50000 map of the Pico Partido area. The author is grateful to Dr Louise Thomas for reviewing a previous version of this paper and for drawing his attention to the work of Carracedo and co-workers on the 1730-36 eruption.

References

Araña V, 1997, *Lanzarote: guia*. Servicio de Publicaciones de Excmo. Cabilo de Lanzarote. 128pp.

Carracedo J C, Rodriguez Badiola E & Soler V, 1992, The 1730-1736 eruption of Lanzarote, Canary Islands: a long, high-magnitude basaltic fissure eruption, *Journal of Volcanology and Geothermal Research* **53**, 239-250.

Carracedo J C & Rodriguez Badiola E, 1991, *Lanzarote - la erupción Volcánica de 1730,* Servicio de Publicaciones Excmo. Cabildo Insular de Lanzarote, 168pp.

Fralick P, 1999. Paleohydraulics of chute-and-pool structures in a Paleoproterozoic fluvial sandstone. *Sedimentary Geology*. **125**, 129-134.

Heslop SE, Wilson L, Pinkerton H & Head III J W, 1989. Dynamics of a confined lava flow on Kilauea volcano, Hawaii. *Bulletin of Volcanology,* **51**, 415-432.

Macias J L, Espindola J M, Bursik M & Sheriden M F, 1998. Development of lithic breccias in the 1982 pyroclastic flow deposits of El Chichon volcano, Mexico. *Journal of Volcanology and Geothermal Research*. **83**, 173-196.

Massey B S, 1970. *Mechanics of Fluids*. Van Nostrand Reinhold, London. 508pp.

Scarth A & Tanguy J-C, 2001, *Volcanoes of Europe.* Terra Publishing, Harpenden. 243pp.

Spera F J, 2000, Physical Properties of Magmas. in: Sigurdsson H, *Encyclopedia of Volcanoes*. Academic Press, London. 1417pp.

Weirich F H, 1988. Field evidence for hydraulic jumps in subaqueous sediment gravity flows. *Nature* **332**, 626-629.

Author

Duncan Woodcock MA, CEng, MIChemE, BSc Hons (Open), FGS is a senior process engineer with ABB Ltd.

Travels to New Mexico and the Four Corners Area. March 2001

Gladys Dinnacombe

The idea for this journey began at the end of 2000 when a group of us decided to meet together in New Mexico and explore the ruins of the ancient cities. In the end, there were only three of us and we did not explore as much as planned. When you are used to living just above sea level, living at 5000 feet higher is less easy and hiking in the mountains is more tiring!

Although the journey began when I flew to Newark on 13th March, it really began on 17th March after an overnight stay at Holbrook in Arizona, having driven from Los Angeles the previous day. We woke early to see a covering of snow on the ground. After breakfast we set off towards the Petrified Forest National Park. As we drove along, the sun started to melt the snow and the mist rose up from the ground. The Petrified Forest is of the Triassic Period and there are many fossils being studied by palaeontologists. This area was once tropical and marshy where amphibians such as *Metoposaur*, once lived. More than 150 different species of fossil plants have also been discovered, the most obvious being petrified wood from which this National Park gets its name.

The rocks of the Petrified Forest area belong to the Chinle Group (late Triassic) and consist of lacustrine and fluvial terrestrial deposits such as sandstones, mudstones, claystones and shales. This group is famous for its fossil fauna and flora including the earliest dinosaurs. Within the Chinle Group (Figure 1), the Petrified Forest Formation consists of:

Painted Desert Member

Sonsela Sandstone

Blue Mesa Member.

Our purpose in visiting this National Park was really to visit the ancient ruins of Puerco Pueblo, the ruins of a 100 room pueblo built before 1400. Petroglyphs can be seen also on some of the larger flat rocks. There is evidence of human occupation for more

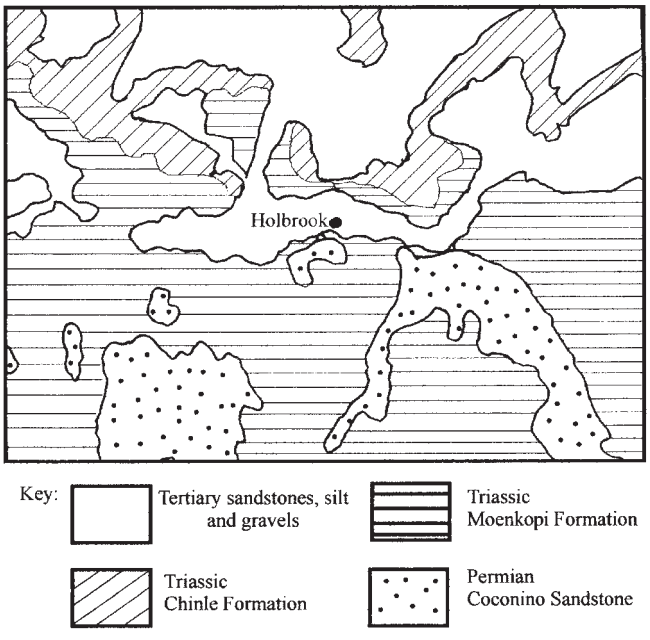


Figure 1. Sketch map of the geology around Holbrook.

Figure 2. Agate Bridge, Petrified Forest.

than 10,000 years in this area and there are more than 600 archaeological sites. People lived on berries and seeds and hunted animals as well as growing corn, beans and squash. They used the clays to make pottery and made tools from the petrified wood. Homes were made from sandstone blocks and petrified wood.

However, we did stop at the Agate Bridge (Figure 2) and studied this wonderful expansive landscape. For those who have never been to countries so large as the USA this kind of vista is hard to describe. It is so vast and you can see for almost a hundred miles in each direction. No photograph can capture this awe-inspiring landscape!

Figure 3. Blue Mesa, Petrified Forest.

Our next stop was Blue Mesa (Figure 3). The Blue Mesa Member is over 300 feet thick in some areas and is composed of blue and lavender bentonites as well as mudstones and siltstones and it is very fossiliferous. There are flat sandstone-capped buttes formed by the weathering of the softer mudstones and siltstones. It is a good example of wind and water erosion on clay hills.

Before continuing our journey to New Mexico we stopped to admire the Painted Desert (Figure 4) which is composed, not surprisingly, of the Painted Desert Member. It rests unconformably on the Sonsela Sandstone and consists of greyish red, brown and reddish purple mudstone, silts and sandy siltstone. Generally the beds are more than 15m thick and the whole member is over

Figure 4. Painted Desert.

Figure 5. View from La Posada.

300m thick in total. White mudstones can be seen capping red bentonites and the rose coloured bentonites are capped with basalt of the Tertiary Biddahochi Formation.

We continued our journey without event until we left Santa Fe and were nearly at our destination; then the sky went black and it began to hail and snow. Traffic slowed and crawled along until the sky cleared and the snow stopped. We eventually came to a turning, the narrow dirt track to our posada (an inn) which, although a bit slippery, was passable. It was nearly dark when we arrived, so we unpacked and fell into a deep sleep!

Awakening early the next day, we first explored the immediate surroundings of the posada. This area is desert and cactus grew amongst the sandy cliffs which we climbed to get the view around. What a wonderful place to be! Mountains with snowy tops, sandy red and pink striped cliffs and small dwellings scattered amongst them.

The landscape of New Mexico is very varied and was caused by many different kinds of geological events. There have been mountain building events, invasions and retreats of seas as well as advancing deserts and volcanic eruptions. Precambrian rocks are exposed in some of the mountain ranges and these include gneiss, schist and other partly metamorphosed sedimentary rocks. These rocks also indicate the presence of volcanoes and huge volcanic eruptions. Granitic intrusions also occurred during the Precambrian. During the Paleozoic, seas advanced across New Mexico and there are many sandstone, shale and limestone deposits from this time. During the Triassic Period, coastal plain, floodplain and delta deposits spread across the area and there were also episodes of volcanic activity. This was followed by a period of desert environment in which the dinosaurs roamed! As they became extinct, North America broke away from Europe and the Rocky Mountains began to uplift which allowed the formation of mineral deposits. As the Tertiary Period approached, the Rio Grande Rift began to sink between two sets of faults and plateaux developed in the west. More volcanic activity followed through into the Quaternary Era together with repeated glacial cycles.

Around our posada the rocks of the Santa Fe Group can be seen (Figure 5). These are of Tertiary age and consist of sediments, lake and stream deposits as well as volcanic ash.

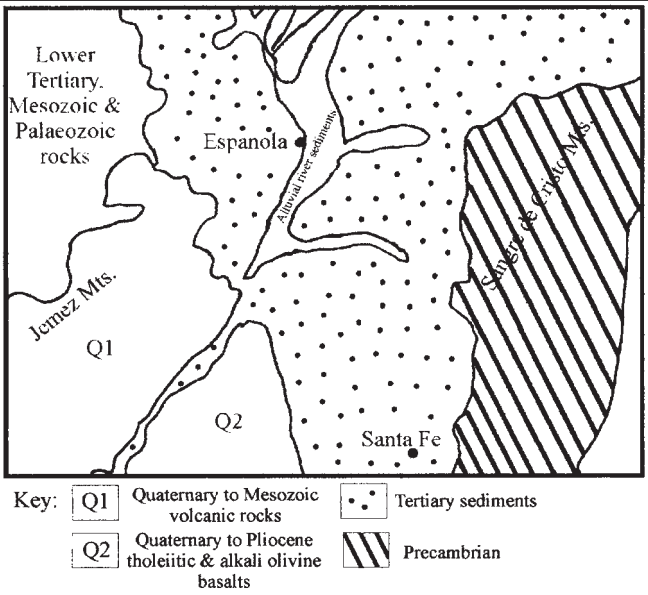


Figure 6. Sketch map of the geology of the Espanola and Jemez Mountains area.

Figure 7. Bandelier and detail of caves.

One day we visited Bandelier National Park. The journey there gave us more inspiring scenery and also some sorrowful thoughts as this was the area devastated by fire which spread very quickly and out of control during last year. In the park we saw the film produced by the Visitor's Centre which set the scene for the rest of the day. The words in the film were spoken by a Native American and were very profound. We then set off on the trail along the canyon.

Figure 8. Pillar at Bandelier.

Twice, about 1.6 million years ago and again about 1.2 million years ago, there was a very large series of volcanic eruptions from the Jemez Mountains near Bandelier (Figure 6). The volcano was a composite volcano, probably the same shape and size as Mount St. Helens before its eruption in 1980. When the Jemez volcano erupted it released about 100 times more material than Mount St. Helens. Ash clouds drifted as far as Texas. Only the base of the Jemez volcano now remains; the rim of the Valles Caldera at the centre of the Jemez Mountains. The caldera created by the collapsed summit of the volcano is amongst the largest of calderas at 24km across. Ash from the explosions and basaltic lava were deposited across the landscape in thick layers creating the Pajarito Plateau. The ash, a volcanic tuff, is pink with a sandy texture. It is porous and relatively soft so that running water erodes it quickly, cutting deep steep-walled canyons like the one in Bandelier known as Frijoles Canyon (Figures 7&8). The ash flow deposited here is from the second eruption of the Jemez Volcano.

Bandelier National Monument was named in honour of Adolph F A Bandelier, a distinguished Swiss-American scholar, who carried out an extensive survey of prehistoric ruins in the region and studied the Pueblo Indians around Santa Fe. Part of his time was spent in Frijoles Canyon (Figure 9).

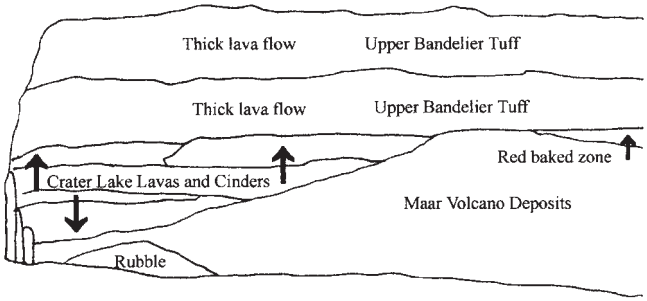


Figure 9. Sketch of Frijoles Canyon.

We entered the ruined village of Tyuonyi. The buldings had been at least two storeys high and contained about 400 rooms which

housed about 100 people. The village is circular in plan and tree ring dating has shown that it was built over 600 years ago. In the cliffs nearby are also many dwellings located along the south-facing canyon, so that in the winter they get the afternoon sun and so are much warmer. There are many rooms in the cliff walls, dug out of the rock which is quite soft. Sometimes the rooms were plastered with clay and soot can be seen on the ceilings indicating fires in the rooms. Some of the houses which are built into, or at the side of, the cliff are known as talus houses. Talus is the rock debris found at the base of a cliff and this debris was used to build the houses. Many of these houses are 3 or 4 storeys high against the wall of the canyon. The holes where the timbers rested to support their houses, can still be seen. Also here are small kivas (sacred places), one of which has rock paintings along the wall in a black zig-zag design which could represent a feathered serpent.

From the path alongside the ruined cliff houses there is a panoramic view of the canyon. The stream below yielded water for crops and you can see small areas which had been farmed. As many as 500 people are believed to have lived here with other villages nearby. Walking further along the trail we came to the Long House. This was a condominium style community which extended for 800 feet along the cliff wall. Above the top row of holes (where roof beams once stood) petroglyphs have been carved into the stone.

Returning to the bottom of the canyon we walked along the stream and pondered on what we had seen. Why did the people choose to live here and why did they leave? They had lived with the earth in a total way, using the cliffs to make homes, using the land around to farm and making pots and baskets from the natural resources around them.

On another day we drove along the road towards Ghost Ranch. Here the scenery is again spectacular, the cliffs forming amazing shapes carved by the wind and rain. The rocks here are Mesozoic and result from many years of erosion along the valley of the Chama River. A tributary of the river has also carved its way into the Entrada Sandstone (Jurassic) exposing the colours clearly. Darker rocks cap the cliffs here and the caps are formed from the Todilto Formation, a composition of limestone and gypsum which it is believed was precipitated from the southern margin of an inland sea during the Middle Jurassic. Talus at the base of the cliffs conceals rocks of the Chinle Group (also seen in the Painted Desert), which underlies the Entrada Sandstone.

Our return journey took place at a better time for viewing the scenery as we drove past. Mount Taylor, an extinct volcano, could be seen as we drove north.

Driving along the I-40 towards Flagstaff, the Hopi Buttes (Figure 10), unusual volcanic conduits known as diatremes, were visible. After leaving Flagstaff, San Francisco Mountain, which last erupted around 220,000 years ago, dominated the scenery. Younger cinder cones were also visible in several places along this route.

After an overnight stay at Williams, our return journey continued through more volcanic rocks into a Precambrian landscape formed by the Hualapai Mountains which consist of granite, gneiss and schist and have sharp peaks and spires (Figure 11).

Figure 10. Hopi Buttes.

Figure 11. Hualapai Mountains.

Figure 12. Granites.

As we got nearer to California, I noticed the change in the scenery. The mountains became more jagged and were not always sedimentary, although many were of limestone. Travelling through the Mohave National Preserve, granite mountains could be seen (Figure 12). These granites are of late Mesozoic age and formed at depth within a volcanically active mountain range. The granites often form tors as seen in Dartmoor, but on a larger scale!

Descending from the Mohave into Los Angeles was a journey not easily forgotten, down winding expressways through snow-capped mountains to sea-level! This whole journey was full of surprises but one I would like to repeat and to also take time to explore more of the geology.

Author
Gladys Dinnacombe has been a member of the OUGS since 1974 and is currently undertaking private research locally and in the USA. She has a BA Hons (Open) and a BPhil (Open).

Darwin's Islands

Philip Clark

My wife and I went to the Galápagos Islands in June 2001 because when we decided to celebrate my 65th birthday it seemed a good thing also to make up for neither of my last two courses, S330, Oceanography, and S365, Evolution, having a Summer School! It was of course a superb trip, and it has been interesting since coming home finding out a bit more about the geology of these "Enchanted Islands" (an early Spanish name for them, because of the strange winds and currents in the archipelago, before they finished up with the Spanish name of their best known inhabitants, the giant tortoises). I wrote a chatty article for Severnside branch's newsletter, Sabrina Times, drawing on some preliminary reading as well as my own rather untutored observations (the Galápagos National Park guide, though excellent on fauna and flora, knew rather less geology than I did). I have now tried to put together for this Journal material from some of the most accessible sources on the islands' geology, and in particular to contrast Darwin's observations with our modern understanding.

Tectonic setting

The Galápagos Islands have been immortalised by Darwin not only for their contribution to his theory of natural selection, but also because they were among the volcanic oceanic islands which he brooded on constantly for many years after the visit of the Beagle in 1835 in relation to their geology and formation. Percipient though he was in many ways, how little could he guess the discoveries concerning plate tectonics! He was indeed one of the first to consider the distribution of volcanoes, and especially of volcanic islands. He noticed a certain regularity in curved chains of islands, and in vents being arranged on a line or set of parallel lines, intersecting nearly at right angles with another line or set of lines. The Galápagos appeared to him to be an example of this, with the lines ranging NW by N and WSW. Echoes of this observation appear in the most sophisticated modern studies of the varying geophysics, geochemistry, and petrology of these islands. (Darwin 1844; White *et al.* 1993)

In fact the Galápagos are where they are and have the characteristics they have because of a presumed mantle plume or hotspot near a constructive plate margin (Figure 1). The Cocos Plate to the north and the Nazca Plate to the south of the Galápagos spreading axis are both being subducted, the first under Central and the second under South America. But they are still growing at the spreading axis, although at a slower rate than the north of east and south of east movement away from the East Pacific Rise (roughly 30mmyr^{-1} in each direction as opposed to more than 70mmyr^{-1} for both the Cocos and Nazca Plates). The R-R-R triple junction is some 800km west north west of the islands, about as far as they are from the South American mainland.The Cocos and Nazca Plates appear to have been formed about 25-30Ma ago when the Farallon Plate on the east side of the East Pacific Rise appears to have broken apart along a pre-existing Pacific-Farallon fracture zone (Hey 1977). A recent OU summing up of the situation is that:

> "It is possible that the initiation of this spreading axis was related to the onset of hot-spot activity, and certain that the axis lay almost directly over the hot spot for about the first 20Ma of its existence." (OU 1991)

The spreading axis runs roughly west-east, and has an offset about 600km long north and east of the islands "which appears to have lagged behind the rest of the ridge when it moved northwards off the hotspot about 5 Ma ago" (McBirney 1993 referring to Hey 1977). This means that although much of the spreading axis is characterised by overlapping spreading centres rather than transform faults (OU 1991), there is a major N-S transform fault dividing the western from the eastern islands, at about 90° 50' W.

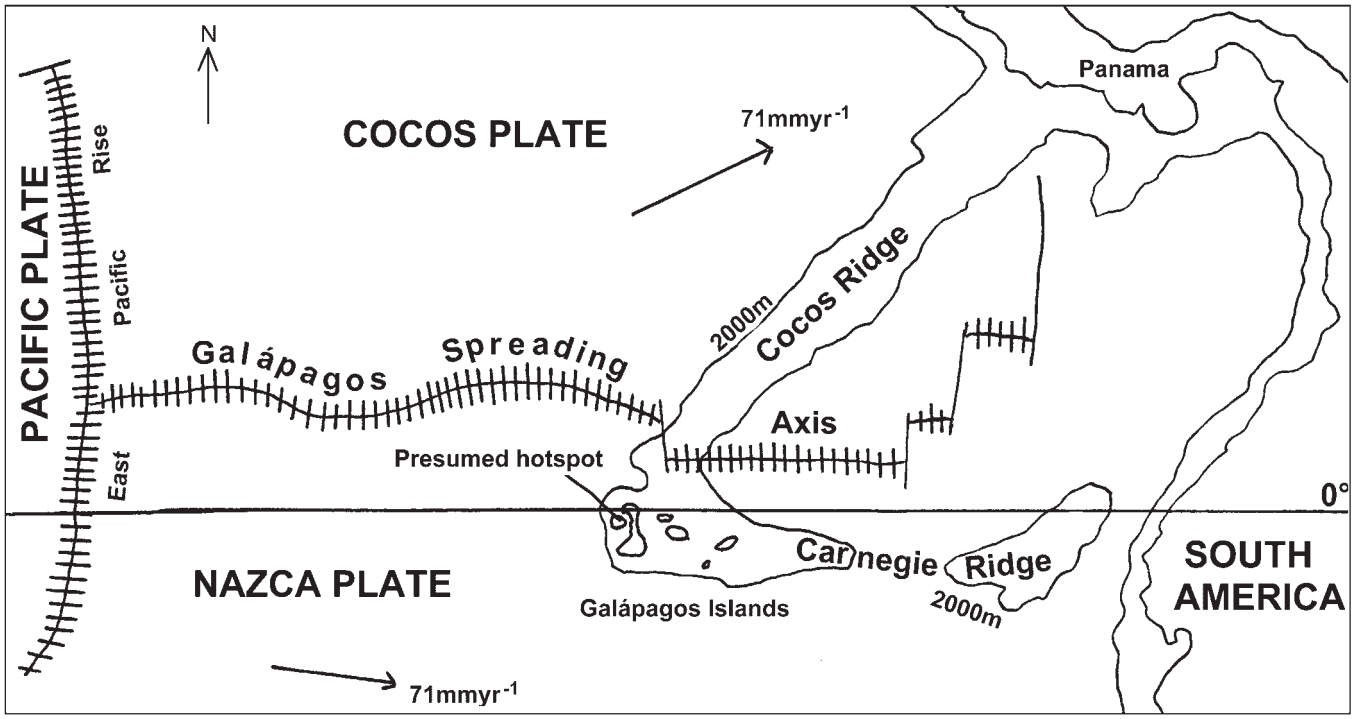


Figure 1. Tectonic setting of the Galápagos Islands.

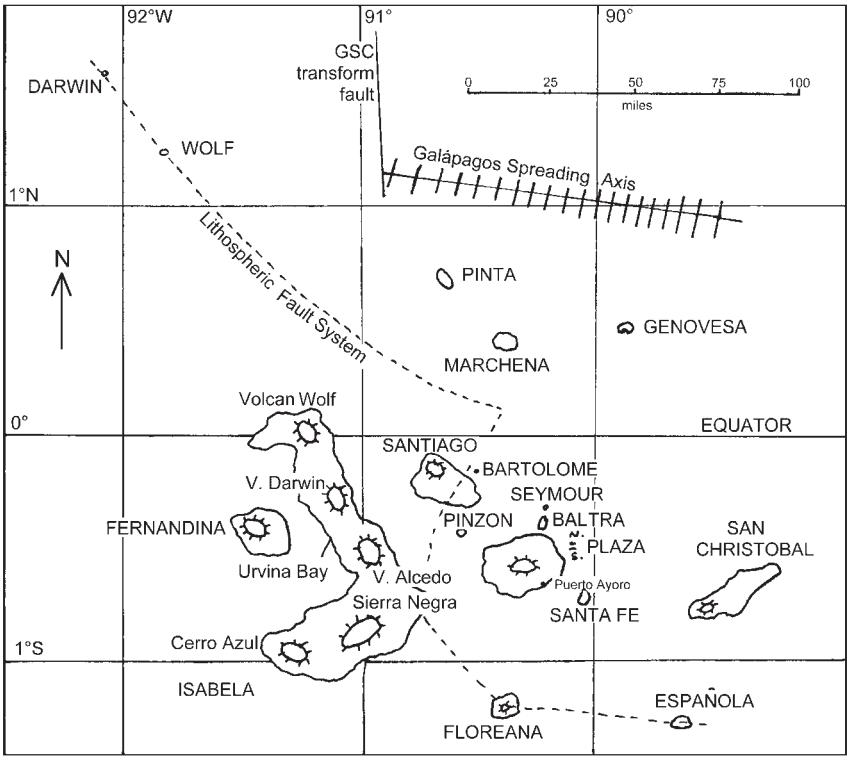


Figure 2. Galápagos Islands with spreading centre and principal volcanoes. (Fault system after White *et al.* 1993.)

The exact position is hard to locate because of the thick sedimentary cover, (McBirney 1993), but gravity data have indicated a lithospheric fault system (extending further to the west) which has implications for the style of volcanism (see Figure 2). The Cocos Ridge and the Carnegie Ridge run consonant with the plate movements north-east and south of east to the mainland from the archipelago; strong evidence that they represent traces of the hotspot. This must be under the western and currently most active volcanoes on the two western islands, the five on Isabela (Albemarle) and the one on its near neighbour Fernandina (Narborough) (all the islands have at least two names, English and Spanish, but I am using preferentially the Spanish names). Simkin (1984) notes that:

> "The shallow submarine platform of the Galápagos archipelago has steep slopes to the west and south, but gentle slopes to the north-east and east where it is essentially the intersection of the Cocos and Carnegie Ridges. This is exactly the physiographic pattern to be expected from a fixed mantle hotspot…."

There are also of course on the spreading axis the first hydrothermal vents to be found in the oceans in 1977, some way east of the archipelago. There were almost certainly earlier islands before the present ones, at least on the Carnegie Ridge, where wave eroded clasts have been found on at least one seamount. This has considerable implications for the evolution of the biota of the Galápagos, if islands have been in the area longer than the few million years of the present ones, and perhaps even at one time nearer the continents.

Dating the islands

There is a considerable problem in dating the island rocks which Simkin (1984 p17) sums up:

> "Young lava flows tend to cover older ones; erosion in most parts of these arid islands is too slow to cut through to the older interior; potassium, the parent element whose radioactive decay to argon is most commonly measured in age determination, is present in only very small quantities in most Galápagos rocks; the dry, rubbly lava flows that make up so much of the Galápagos have daunted much diligent searching for the islands' oldest rocks."

Also, according to Dennis Geist (pers. com.):

> "All of the Galapágos are very young and erosion is extraordinarily slow, so the guts of the volcanoes are never exposed".

Except in El Niño years, the islands have a mild, dry climate for much of the year, and the north sides are normally in a rain shadow even in the wet season.

But the ages are known well enough for us to be sure that the ages of the islands do not have a neat linear progression, like those of the Hawaiian Islands. This may be because the spreading axis and especially the transform fault complicate the products of the hotspot. The oldest flows at each of the islands, so far as these can be still recovered, do however "form a reasonable progression from youngest in the west to oldest in the east" (White *et al.* 1993). Seafloor dating suggests that the hotspot is at least 25Ma old and the crust on which the western islands stand about 10Ma and that to the east 5Ma. The oldest rocks on the islands, on Española (Hood), have been dated around 3.3Ma. Dates of about 2.4Ma are accepted for San Christobal (Chatham) and 2.6-2.8Ma for Santa Fé (Barrington), both eastern islands. (Cox 1983 quoted by Simkin 1984). These islands have had a remarkably long period of volcanism, 2.4 and 2Ma respectively. The central islands have rocks in the range 0.7-1.5Ma old and the historically active western islands have no dated rocks older than 0.78Ma older (that is, than the Brunhes normal polarity). Over 90% of the surface of Sierra Negra on Isabela is younger than 4500 years, judging from cosmic ray exposure ages of lavas. "Most island fossil deposits are not older than 2 million years," quotes Simkin (1984 from Lipps and Hickman 1982), who also notes that "the prominent lava flow in James Bay contains fragments of marmalade pots stashed by buccaneers in 1684…. The flow was mentioned by Darwin, thus bracketing its age between 1684 and 1835: one of the rare uses of marmalade pots in volcano-chronology" (p18).

Eruptions

Historic eruptions (since 1500) have occurred on Marchena, Santiago and Pinzon besides the great western Galápagos volcanoes. The oldest documented eruption was from Volcán Wolf (Isabela) in 1797, followed by one on Fernandina or possibly the nearby Volcán Darwin in 1813. This was reported by Captain Porter of USS Essex: "A volcano burst out with great fury … At night the whole atmosphere was illuminated by it, and yet we could perceive neither flames nor sparks thrown out by the centre", probably because activity was contained within the summit caldera. The most violent outbreak seems to have been that on Fernandina in 1825, graphically described by Captain Benjamin Morrell in *A Narrative of Four Voyages in the South Seas* (1832) and quoted in Eibel-Eibesfeldt (1960):

"The sublimity, the majesty, the terrific grandeur of this scene baffle description and set the powers of language at defiance. Had the fires of Milton's hell burst its vault of adamant and threatened the heavens with conflagration, his description of the incident would have been appropriate to the present subject … Had it been 'the crack of doom' that aroused them, my men could not have been sooner on deck, where they stood gazing like "sheeted spectres" speechless and bewildered with astonishment and dismay…" They don't write like that now.

Indeed, the large shield volcanoes on the western islands "taken together constitute one of the most active volcanic regions in the world" (McBirney & Williams 1969). Fernandina had 17 eruptions between 1813 and 1984, erupted again in 1991 and most recently in January-February 1995 when lava flowed 5km to the sea. At least 15 eruptions took place on Isabela between 1911 and 1979: five on Cerro Azul, four on Sierra Negra, one on Alcedo, five on Wolf, none on Darwin. There have been several since. In the eruption on Sierra Negra in November 1979 tephra fell on the villages of Santo Tomás and Villamil, 13 and 26km SE of the eruption site, within twenty minutes of the first explosion. What is unusual for a mantle plume site is that there are so many active volcanoes – nine have been active historically and 14 or 15 different ones have erupted in the last ten thousand years on land and others below sea level, compared to only six on The Hawaiian Islands. In Margret Wittmer's book *Floreana* (the strange tale of the Germans on that island in the 1930s and who murdered who is not relevant here) - there is a good account of seeing "a gigantic mass of flame rising into the dark sky to the north-west" in 1944. This eruption of Cerro Azul on Isabela had been presaged on Floreana 65km away, by a strange day of heaviness for both humans and dogs, a smell of sulphur and an oppressive silence. The oldest lavas on Floreana (Charles) are 1.5Ma old, making it one of the older islands – Margret Wittmer thought that "Floreana was a very young island, only a few hundred years old"!

Figure 3. Volcán Darwin, Isabela, showing 'soup-bowl' shape.

Style of volcanism

The large western volcanoes have an "inverted soup-bowl" shape, that is, steep-sided shields (Figure 3). This is quite unusual and the origin may be due to most of the vents occurring on circumferential fissures near the flat summits. Simkin (1984) points out that "circumferential vents, like calderas, are a consequence (albeit special) of near-surface magma chambers". The consequences of the vents – growth of a circular ridge, gravitational stresses, distending of the ridge by dikes in the feeding fissures, ponding of lava behind cones on the ridge – are the soup-bowl shapes. The mostly older volcanoes on the islands to the east are smaller and have gentler slopes. This difference appears to be due partly at least to lithospheric thickness. The fracture zone in the spreading axis near 91°W runs, as said above, roughly between the western islands and the rest, and as the plate margin is further north to the west, the oceanic crust is older and thicker under Fernandina and Isabela and better able to bear the weight of a large volcano. The lithospheric fault system indicated by gravity surveys perhaps refines this concept (White *et al.* 1993). McBirney & Williams (1969) point out that on Isabela and Fernandina there are no large parasitic cones comparable to those on the major central and eastern islands. They comment:

"This lack of large pyroclastic cones probably indicates that the great shield volcanoes are at present in the mature stage of rapid growth, like Mauna Loa on Hawaii; i.e. thin, wide-spreading flows of tholeiitic basalt accompanied by small cones of scoria and spatter built along eruptive fissures. During later stages of growth, thicker flows tend to accumulate and ultimately fill the summit caldera, their composition changing gradually from tholeiitic to alkali-olivine basalts. Still later, during the Mauna Kea stage of evolution, more varied types of material are erupted, and in general explosive activity becomes more pronounced while intervals between eruptions become larger." (p77)

Figure 4. Caldera on Sierra Negra, Isabela.

Calderas

These shield volcanoes have very impressive calderas on their summits (Figure 4). Darwin wrote in his diary:

"The east side of Albemarle [i.e. Isabela] island is nearly black with recent uncovered lavas. The main hills must have immense Cauldron like Craters, their height is considerable – above 4000 feet: yet from the outline being one uniform curve, and the breadth of the mountain great, they do not appear lofty." (Barlow 1933 p342; Keynes 1988 p363-4).

In 1857 Darwin was still lamenting, in a letter to Lyell, that he had not been "able to examine the great craters on Albemarle Isd" (Burkhart 1996). We were more fortunate and went up to the one that is accessible to visitors, Sierra Negra. It is billed in the tourist literature as "the largest in the world after the Ngorongoro caldera in East Africa"; at 10x7km it is indeed large and impressive, but

Las Cañadas on Tenerife is a caldera of 10x17km, and there are several other calderas around the world larger than Sierra Negra. Sierra Negra, though the largest in area on the Galápagos, is also the shallowest, at 100+m. The deepest caldera is on Fernandina: "an awesome steep-walled pit", McBirney and Williams (1969) call it. It was the site of the last major caldera collapse, in June 1968, dropping 350m in approximately 75 increments over nine days, to a total of 1120m – very deep for a shield volcano: the total height of the volcano is 1495m. The collapse was preceded by a major eruptive explosion, with a cloud more than 15km high seen throughout the archipelago, followed by a major earthquake swarm. The caldera floor subsided intact, but with the greatest drop at the south-east end where a large lake had formed (Simkin 1984). More of the wall there collapsed in 1984, in the fourth eruption since 1968. Land iguanas inhabit the upper slopes, and nest in the caldera. They build their burrows in the relatively soft 1968 phreatomagmatic ash. Unfortunately this is not a site accessible to the normal tourist: the whole of Fernandina is a Maximum Protection Zone category of the National Park and only the Visitors' Site at Punta Espinosa can be visited (well worth it for the endemic and often nesting flightless cormorants!). Practically all the rest of the archipelago is classed as Primitive Zone, and visitors are quite rightly confined to the Visitors' Sites and must have a Park guide.

Tectonic uplift

On Floreana (Charles) and San Christobal (Chatham) Darwin considered many of the volcanic features to have been submarine, implying tectonic uplift, and indeed some portions of the Galápagos are there for that reason and not because of volcanic activity. You see this on the very first island normally visited, Seymour, next to the airport on Baltra. Both these islands have fossiliferous limestone between lavas. From your boat the low cliffs look like illustrations of the formation of oceanic crust – small dykes feeding pillow lavas. As you pick your way among the nests of the blue-footed boobies on the little island you recognise pillow lavas scattered around the surface. These were not yet a feature identified by geologists in Darwin's time (the phrase came in the 1890s, according to the OED Supplement). They appear again later on when you land on Plaza Sur (where I tossed an Opuntia fruit, quite against the National Park rules of course, to a grateful land iguana which had been waiting under the wrong tree).

McBirney & Williams (1969) describe the main uplifted tectonic blocks as follows (p9ff; I summarise): The two small Plaza islands are detached parts of the north-eastern coast of the large island of Santa Cruz (Indefatigable), this coast consisting of north-dipping basaltic flows, tuffs, and marine sediments uplifted onto an island which is mostly a broad shield volcano. Española (the breeding ground for the whole Pacific population of the waved albatross) is a block of uplifted submarine lavas 16x8km. Santa Fé is a roughly rectangular horst 3x2km, a group of gently tilted and flat fault blocks of basalt lavas uplifted from below the sea. Simkin (1984) adds to tectonically-formed areas the important bay and village of Puerto Ayoro, one of the two main towns on the archipelago. A down-dropped block is responsible for the cliff to the south of the inner harbour which formed a backdrop for us for the arresting sight of sardine leaping out of the water because chased by larger fish, but being caught in mid-air by boobies! To the north, behind the tortoise pens of the Charles Darwin Research Centre, is the corresponding cliff. Most dramatically tectonic uplift occurred in 1954 on the western side of Isabela at Urvina Bay. The seabed rose as much as 4m above sea level and 6km of coastline were affected. Suddenly several square kilometres were added to the land, and many marine creatures stranded. You can still see coral "heads" and the skeletons of turtles, although the flat plain is now thickly vegetated, to the pleasure of the first giant tortoises and land iguanas we saw. This uplift has been interpreted as being connected to an eruption on the nearby Volcán Alcedo, but is now considered more likely to be related to an eruption on Sierra Negra, over 40km south of Urvina Bay. Simkin (1984) points out that all faulting has apparently been normal, "as should be expected from the extensional tectonic setting". All these recent block-faultings and uplifted submarine lavas, except for Urvina Bay, are along or near a possible projection south-south-eastwards of the transform fault mentioned above (McBirney 1993).

Petrology

Darwin had little more to say on Galápagos mineralogy than that there seemed to be more albite in the basalts in the northern islands than in the south (Darwin 1844). The strongly differentiated rocks on the archipelago, we now know, are rare and are rhyolites and trachytes; but he "did not meet with a single specimen of true trachyte", and was surprised not to find (rhyolitic) pumice as the albite seemed the same as in the Cordillera of South America. Geist (pers. com.) says: "Galápagos rocks generally plot darn near on the dividing line on an alk-silica plot," and in fact the Galápagos are exceptional geochemically among ocean islands, because "while most basalts have typical OIB incompatible element concentrations and isotope ratios, basalts that are essentially indistinguishable from MORB in their geochemistry are also common products of Galápagos volcanos" (White *et al.* 1993). Alexander McBirney has considered the relation of geochemical data to the central E-W axis of the island chain which is presumably the line of movement over the hotspot as the islands drifted eastwards with the Nazca Plate. This followed speculations he and Ian Gass had been making since the late 60s about the "the curious spatial relations of the rocks of oceanic islands to mid-oceanic ridges". In the Geological Society volume in commemoration of the work of Ian Gass (McBirney 1993), he concludes that "extensive differentiation has been confined to volcanic centres near the central axis of the Galápagos Platform, with tholeiitic rocks close to the centre giving way to more alkaline trends toward the margins". Few primitive basalts, but all the differentiated series, are found west of the presumed extension of the transform fault, that is, on older lithosphere further from the spreading centre. McBirney points out that Volcán Alcedo lies immediately downstream from the presumed core of the hotspot under Fernandina, and is the only one of the six great western volcanoes to have an extensive flow of rhyolitic lava on the caldera floor and a blanket of rhyolitic pumice on its flanks. (We saw some of this at Urvina Bay, to the west, but nothing approaching the 2.5m thickness of the eastern coastline.) The Cornell website (written mostly by W M White) says of Floreana, well to the south of the axis, that it

> "represents one extreme of the range of lava compositions encountered on the islands. Basalts here are distinctly more "alkalic" in composition, as opposed to the more "tholeiitic" compositions produced by most [Galápagos] volcanoes. "Alkalic" magmas are often richer in water and CO_2, gases that drive explosive eruptions. Thus the compositional difference

probably accounts for the abundance of pyroclastic cones. Trace element abundances in these lavas indicate that Floreana magmas are produced at shallower depth in the mantle and by smaller extents of melting than in the rest of the archipelago. This may well reflect its position on the southern periphery of the archipelago, where the Galápagos Mantle Plume is cooled by contact with surrounding mantle".

It is thought to be plume-asthenosphere mixing which accounts for much of the observed geochemical variation, unique among oceanic island groups (White *et al.* 1993).

Volcanic features

Darwin (1839) observed that there must be at least two thousand craters on the islands, of two kinds. One, "in the ordinary cases" of scoria and lava, "the other of finely stratified volcanic sandstone" (p 453). Floreana (Charles) is certainly the island most densely crowded with parasitic cones, scoria, lava-scoria and tuff. Darwin wrote in his diary: "Small as the whole island is, I counted 39 conical hills, in the summit of all of which there was a more or less perfect circular depression. It is long since the Lava streams which form the lower parts of the island flowed from any of these Craters" (Barlow 1933 p338; Keynes 1988 p356). And I think he took the tuffs, which he called elsewhere "hard sandstones composed of volcanic dust" to derive their form from a subaqueous origin. It is remarkable that at his age (26 when he was in the archipelago) and with his small experience of volcanism before he sailed (a visit with Sedgwick to Snowdonia!) his observations were so accurate in the main. He took, it is true, the first volume of Lyell's Principles of Geology with him, which includes discussion of volcanoes. The newly published second volume caught up with him at Montevideo nearly a year later, and the third later still. Of course, by the time he published *Geological Observations on the Volcanic Islands*...(1844) he had had eight years back in Britain and was an accepted geological expert – vice-president indeed of the Geological Society, having become an unwilling Secretary in 1838. *Volcanic Islands*, like its predecessor *Coral Reefs,* had come "half out of Lyell's brains". "It cost me *18 months!!!*" he moaned to Lyell, yet few had bought it.(Desmond & Moore 1991). It was, he considered, the tuff-craters, "from the peculiarity of the resin-like substance which enters largely into their composition [?], from their structure, their size and number, [which] present the most striking feature in the geology of this Archipelago" (Darwin 1844 p192). A modern assessment like White *et al.* (1993) shows the immense distance geology has travelled in 150 years, with its list of mainly geochemical and petrological areas in which the Galápagos are peculiar.

Figure 5. Nested craters on Bartolomé.

Figure 6. Aa and pahoehoe lava on Bartolomé.

Despite what Geist says about the lack of erosion, some cones on the coast have been sliced downwards to produce striking cliffs, particularly notable on the north coast of Santiago (James), and distinct lava flows are obvious. On Bartolomé you can look down to the shore and see the circular outline of a small cone at sea level nested inside a slightly larger one (Figure 5), which reminded me of the Fife coast Carboniferous sites visited on the S339 summer school – but without the visible "plumbing" or "guts". Most of the lava flows are aa, but in a number of places commonly visited, like Sullivan Bay (Santiago) and Punta Espinosa (Fernandina) there is excellent ropy lava, pahoehoe (Figure 6). Darwin had been struck by the fluidity of some of the lava flows to which this witnesses, comparing flows on Albemarle (Isabela) and James (Santiago) with some on Chatham (San Christobal). (He only personally visited these three islands and Charles (Floreana), although other members of the Beagle crew collected specimens elsewhere.) In *Volcanic Islands* (Darwin 1844) he wrote:

> "The degree of fluidity in different lavas, does not seem to correspond with any apparent corresponding amount of difference in their composition: at Chatham Island, some streams, containing much glassy albite and some olivine, are so rugged, that they may be compared to a sea, frozen during a storm; whilst the great stream at Albemarle Island [at Tagus Cove] is almost as smooth as a lake, when ruffled by a breeze. At James Island, black basaltic lava, abounding with small grains of olivine, presents an intermediate degree of roughness; its surface being glossy, and the detached fragments resembling in a very singular manner, folds of drapery, cables, and pieces of the bark of trees [original punctuation]." (p105)

In many places on the islands there are littoral cones, formed when a lava flow entered the ocean. Strong explosions from the combination of hot lava and ocean water fragmented the lava and threw the debris onto the coastline on each side of the flow. With the preponderance of basalt rock there are many black sand beaches; but Gardner Bay, for example, is a strikingly white sand beach at the east end of Española. This is partly of course because there are many shell fragments. On Floreana there is a green beach of olivine sand – at least that's what the brochure says – I could only find a few small crystals! On the most inhabited island, Santa Cruz (Indefatigable), the bulk of the volcanic edifice began perhaps 700,000 years or so ago. With time, volcanism became focused along an ESE-WNW fissure system that now defines the crest of the island: we visited "Los Gemelos", "the twins", two

striking pits like mini-calderas, with the lava flows clearly exposed. The Cornell site points out that judging from the lack of soil between the flows, development of the volcano must have been quite rapid. Darwin's usual accurate observation was shown on Chatham where he commented on similar but smaller features:

> "There are large circular pits, from 30 to 80 feet deep, which might be mistaken for Craters, but are in reality formed by the subsidence of the roofs of great caverns, which probably were produced by a volume of gaz [sic] at the time when the Lava was liquid" (Barlow 1933 p335; Keynes 1988 p354).

Conclusion

Darwin, who had compared the small cones on Chatham to "an industrial wasteland" or "the Iron furnaces near Wolverhampton", left the Galápagos commenting (on Isabela) "I should think it would be difficult to find in the inter-tropical latitudes a piece of land 75 miles long, so entirely useless to man or the larger animals" (Barlow 1933 p343; Keynes 1988 p360). It is ironical that his later work on natural selection has rendered them one of the most important spots on earth and those who have followed his pioneer vulcanological investigations have been not less significant.

References

Barlow N (ed.), 1933, *Charles Darwin's Diary of the Voyage of HMS Beagle,* Cambridge University Press.

Burkhart F (ed.), 1996, *Charles Darwin's Letters, a selection 1825-1859,* Cambridge University Press.

Cox A, 1983, Ages of the Galápagos Islands, In: *Patterns of Evolution in Galápagos Organisms,* Bowman, R.I. *et al.* (eds.) American Association for the Advancement of Science.

Darwin C, 1839, *Journal of Researches… (Voyage of the 'Beagle'),* Henry Colburn – many reprints of revised edition, 1845/60.

Darwin C, 1844, *Geological Observations on Volcanic Islands,* Smith, Elder.

Desmond A & Moore J, 1991 *Darwin,* Michael Joseph, London.

Eibel-Eibelsfeldt I, 1960, *Galapagos,* MacGibbon & Kee, London.

Hey B, 1977, Tectonic evolution of the Cocos-Nazca spreading center, *Geological Society of America Bulletin*, **88**, 1404-1420.

Keynes R D (ed), 1988, Charles Darwin's *Beagle* Diary, Cambridge University Press.

Lipps J H & Hickman C S, 1982, Palaeontology and geologic history of the Galápagos Islands, *Geological Society of America*, Abstracts for Annual Meeting, 548.

McBirney A R & Williams H, 1969, *Geology and Petrology of the Galápagos Islands,* Geological Society of America Memoir, 118.

McBirney A R, 1993, Differentiated Rocks of the Galapagos hotspot, In: Prichard H M et al., *Magmatic processes and Plate Tectonics,* Geological Society Special Publication.

Simkin T, 1984, Geology of Galápagos, In: Perry, R (ed.), *Galápagos (key environments)*, Pergamon Press.

OU, 1991, S330, *Case Studies in Oceanography and Marine Affairs,* chapter 5.

www.geo.cornell.edu/geology/GalapagosWWW/GalapagosGeology.html - Galapagos Geology on the Web: last revision 2 Oct 1997 by W M White.

White W M, McBirney A R & Duncan A R, 1993, Petrology and Geochemistry of the Galapagos: Portrait of a Pathological Mantle Plume, *Journal of Geophysical Research,* **98,** 19,533-19,563.

Wittmer M, 1961, *Floreana,* Michael Joseph, London; pb, Anthony Nelson, Oswestry, 1989.

-Also used: personal communications from Dennis Geist, University of Idaho, whom I contacted on the advice of the Charles Darwin Research Centre.

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Author

Philip Clark, BSc Hons (Open) is a retired Dry Stone Waller; his interest in geology sprang from questions concerning the stone he was using. He graduated in Natural and Earth Sciences in December 2001, holds an Oxford MA in Modern History and Theology and is a former Church of England clergyman. He was elected Severnside Branch Organiser in 2002.

Book review

Origins – The Evolution of Continents, Oceans and Life by Ron Redfern, 2000, Cassell & Co, 360pp, £35.00 ISBN 0304354031.

My local library got me this; I saw it reviewed in "New Scientist" magazine. It's the ultimate coffee table Earth Science book, going from the formation of the Earth to the 15th century in 12 chapters. The photos are fabulous – great double-page wide angle aerial shots on most pages with a palaeoglobe showing the positions of the continents at that time and usually a flat, more detailed map of the area of interest. This is the most easy-to-understand coverage of the assemblage of the various continental fragments that made up the UK that I have seen. I've been to lectures and read other books but I feel I have finally grasped the closure of Tornquist's Sea, the Iapetus and Rheic Oceans. There are lovely shots of locations that you have probably seen, e.g. Borrowdale in the Lake District illustrates the section on "Iapetus Destruction", whilst "Last of the Rheic" features Kynance Cove on the Lizard in Cornwall.

Origins is so much more than pretty pictures; each 2-page spread on a single topic has bullets of information which any educated person could use to learn some Earth Sciences pretty effortlessly. In addition, there are interspersed dense pages of text with all the scientific names and details so you only have to plough through the sections that interest you most. These bits are serious; in addition to the Index, there is a 15-page Glossary and a 6-page Bibliography. The book gives a smattering of history too, for example it opens with an account of the death of Alfred Wegener, the maverick who largely invented the concept of plate tectonics.

I know that £35 is a lot of money but this book is worth every penny. Even non-scientific types will be wowed by the photos. The opening shot of the midnight sun in the Canadian High Arctic or the Losvik Mountains (where?) Northwestern Spitzbergen are just stunningly gorgeously scenic. Places you know well, such as Stair Hole, Dorset and others you've probably never heard of before but will want to visit after seeing the pictures and reading about them. Insist on it for your birthday. Nag the library to get it in for you. You'll thank me for it.

Heidi Barnes BSc Hons

Flash flooding and its relationship to the geology of Surigao del Norte, Philippines

Jim Galvin

Introduction

Flash floods have been a concern to many generations; certainly it was recognised by the First Century AD that to build on sand could be perilous (Matt. 7:24–27). Even now, rarely are most people fortunate enough to have houses built on foundations of stone, but we can see that the effects of flash flooding have been in Mankind's thoughts for many generations, probably since before biblical times.

Remembering Lynmouth

The 15th of August 2002 was the 50th anniversary of the worst flash flood in British history at Lynmouth, north Devon (Delderfield 1953). This extreme event killed 34 people and washed away much of the north Devon coastal town as millions of tons of boulders, sand and mud were carried down the steep incised valleys of the East and West Lyn rivers after more than 200mm of rain had fallen on Exmoor during the previous 24 hours (McGinnigle 2002). However, the relatively cool climate of Britain makes flash flooding a rare event; though in parts of the humid tropics it is an ever-present risk.

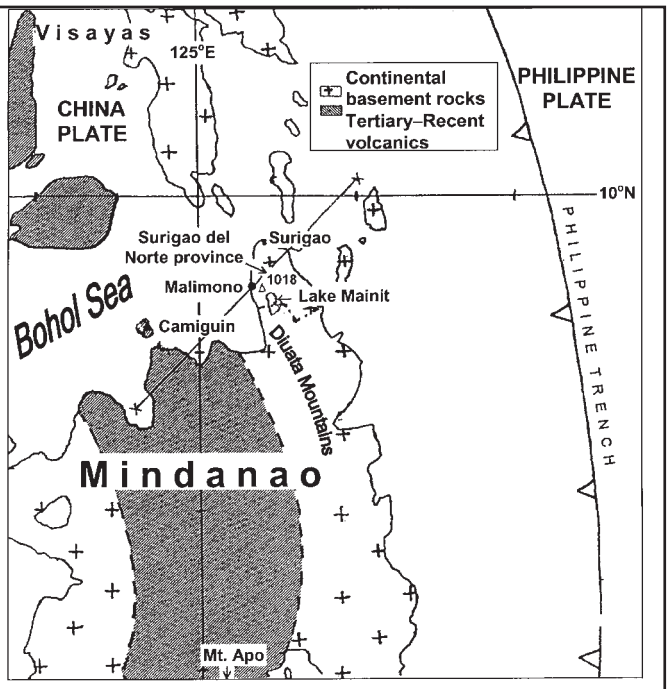

Figure 1. The geology and geography of the north-east of the island of Mindanao, Philippines.

Philippines flash floods

The flash floods that occur in the Philippines are rarely as severe as those that affected the people of Lynmouth but they are more frequent and still have a significant effect on the people affected by them.

The Philippine archipelago is a complex group of over 700 islands forming part of the so-called "ring of fire" that surrounds much of the Pacific Ocean. Many of the islands are volcanically active, situated above a major subduction zone in the humid wet western equatorial sector of the ocean, and occasional earthquakes are also experienced.

A recent trip took me to the island of Mindanao, the nation's second largest island. In the province of Surigao del Norte, the effects of flash flooding in the wet autumn of 2001 were very evident. The province is part of the north-eastern peninsula of the island and many of its dirt roads had been subject to flash flooding. This had caused several of the narrow wood-plank bridges or small-diameter concrete-pipe gullies beneath roads to be washed away. Indeed, occasional heavy rain continued to create transport difficulties during December 2001.

In the current economic state of the Philippines, road repairs often take many years to complete and long periods of traffic disruption are common. Although comparatively few vehicles use these roads, compared to the highways of much of Europe, there is a great need to maintain communications along them. Many of the local people must travel to local towns or cities along them to school, work or the shops. Even the nearest telephone may be in a neighbouring village. Indeed, the unscheduled, but important local form of bus - the "Jeepney" - is much used. Without the highway, the barangays* of the coastal strip would soon be unable to support their populations of fishermen, cash-crop farmers and commuters who work in the city of Surigao.

The geology and topography of north-eastern Mindanao

Even basic geological maps of the Philippines could not be obtained by the author. However, examination of the local geology reveals why the area south of Malimono (9.55°N, 125.45°E) is often subject to flash flooding (see Figure 1). Much of the eastern part of the island is composed of deep crustal rocks: mainly granites and diorites, with some metamorphosed country rocks and the basalt remnants of occasional volcanic pipes, as can be confirmed by examining the pebbles of the beaches of this area (Figure 2). The predominant granite is a coarsely crystalline rock, formed of feldspar, quartz and biotite mica, that forms massive outcrops. The proportion of each mineral was estimated from samples inspected to be about 75% white feldspar, 20% greyish glassy quartz and 5% biotite.

Figure 1 also shows that this part of the island is bounded to the east by the Philippine Trench, where the Pacific Ocean (more accurately, the Philippine Plate) is being gradually subducted beneath the shallow seas at the eastern edge of the China Plate (Open University 1989a 3.3; Brown 1990). To the west is the central volcanic massif of the island, marked by several active volcanoes, including Mount Apo (2954m) in the south – the highest

* Barangay (\bæræŋgä_\) is the Pilippino name for a small village, administered by its residents, who elect representatives regularly. Many of the buildings are self-built homes. An elementary school, taking children between the ages of 7 and 12 and a church, are usually part of the barangay. It has many similarities to the Brazilian favela or Mexican barrio.

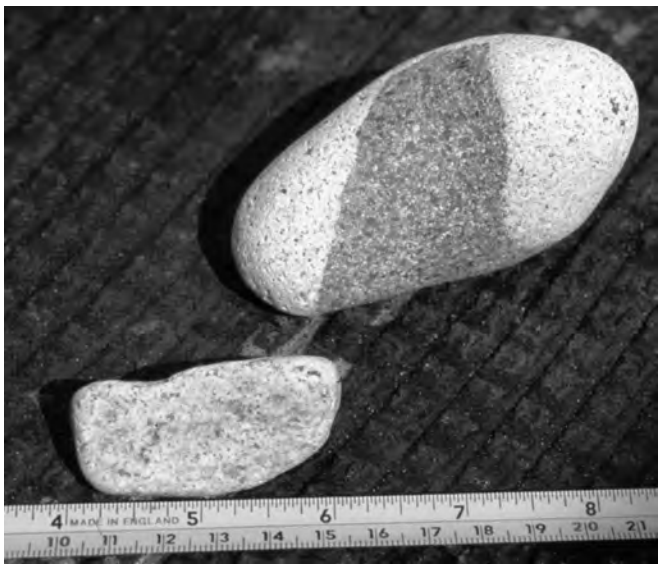

Figure 2. Pebbles typical of the geology of Surigao del Norte from Cayawan beach, south of Malimono. The larger pebble contains diorite as an inclusion in a vesicular fine-grained granite. Occasional metamorphic rocks are also present among the shoreline deposits. [© J F P Galvin]

mountain of the Philippines – and Camiguin, an island off the north coast that forms a classically shaped basaltic cone. Indeed, a major axis of Tertiary folding and faulting runs through the central part of Mindanao (Bartholomew 1953).

The Diuata Mountains of the north-eastern peninsula rise steeply from the beach to above 800m, one peak just south-east of Malimono reaching 1018m. The average slope of the western side of these mountains is about 10° and the upper reaches of river valleys have precipitous slopes of 20-30°. These are very much steeper than most mountain streams or rivers in Europe for example, and contribute to the significant risk of flash flooding in Surigao del Norte. The rock is generally impermeable, although cracks that develop as the pressure on it decreases after its rise through the crust may allow small amounts of water to be stored, promoting erosion of the rock by the acids normally present in rainfall. Thus, as was the case in Lynmouth more than 50 years ago, where the Early to Middle Devonian sandstone and mudstone sediments of Exmoor had been exposed to several periods of heavy rainfall during early August (McGinnigle 2002), prolonged periods of high rainfall can be an important contributory factor in the occurrence of flash floods, which are by no means confined to the desert areas we often associate with them (Highland *et al.*, 1997).

The western coastal plain of Surigao del Norte is rarely more than about 3km wide and is composed of an agglomeration of boulders, gravel, sand and clay, lying over the impermeable base. The soils are very thin, mainly composed of poorly sorted sediments, principally silt and sand with gravel. Indeed, it is likely that this coastal plain is formed by frequent episodes of flash flooding from the braided streams and small rivers of the area (see Open University 1983 6.3.2 & 6.4.2). The steepness of the slopes means that there is little chance for sorting of material eroded from the mountains. Year-round rainfall keeps these shallow overlying sediments of the coastal strip saturated.

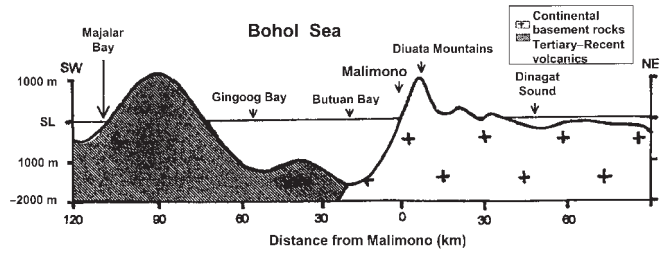

Figure 3. Approximate cross-section through the north-eastern peninsula and along the northern coast of Mindanao, Philippines. Note the Tertiary granites and diorites of the east of the section lying next to younger basaltic rocks of the volcanic central portion of the island.

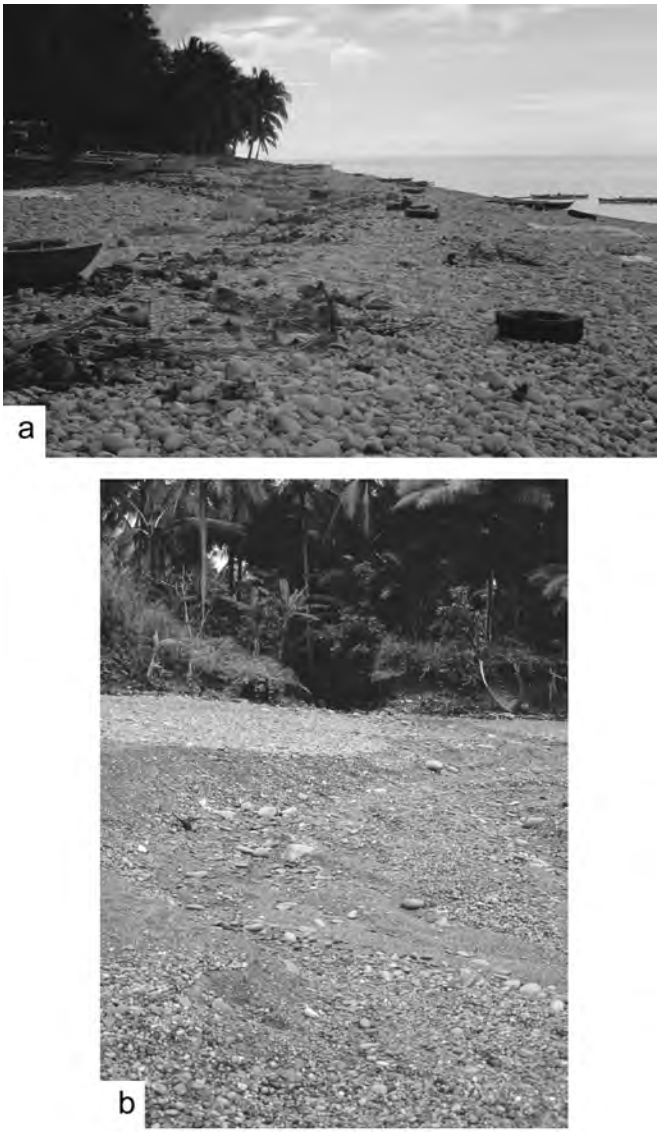

Figure 4. (a) The "step" form of the beach at Cayawan barangay, south of Malimono, Surigao del Norte, Philippines, the top level formed during tropical storms and typhoons. This highest level is about 3 metres above sea level. (b) The poorly defined mouth of a small river that has scoured a beach on the southern outskirts of Malimono, Surigao del Norte, Philippines. These small streams are typical of the area and are likely to be easily overwhelmed during heavy rainfall, perhaps especially near the beach. [© J F P Galvin]

The local drainage pattern and resulting damage

Rainfall runs rapidly westward off the mountains down these shallow streams to the Bohol Sea (see Figure 3). With what may be reasoned has been a rapid rise of this land mass, given the Tertiary age of the rocks and their crystallisation deep in the crust, the river valleys are steep and easily flooded, no equilibrium between the rate of rise and that of erosion having been reached.

Annual rainfall onto the Diuata Mountains is in excess of 3000mm (Bartholomew 1953). Heavy rains, frequent between November and February, or associated with occasional tropical depressions between May and December, easily flood these valleys. The likelihood of flooding is possibly worsened by the "step" beach and the flow of much of the river water between its pebbles that make the lowest part of the valleys very poorly defined (see Figure 4 a&b). This step is formed during tropical depressions and typhoons, when the sea level may rise as much as 3m above its mean (see Open University 1989b 2.4.2).

The damage to the roads is caused in a number of ways, partly due to bad planning of the drainage systems, but mainly due to a lack of investment in the road system. Much of the roadway along the western coast of the peninsula is of stones and dirt. Most streams and rivers are crossed on unsecured wooden planks (similar to railway sleepers) that bridge a relatively narrow gap across the current course of the river between small embankments (Figure 5). Smaller streams drain beneath the roadways through concrete pipes of about 1m diameter, held in place only by small embankments of poorly sorted boulders and gravel.

When the streams and rivers are in spate, these bridges are easily overwhelmed. Debris, mostly the remains of coconut and banana trees, uprooted or occasionally illegally felled, will block the gaps, particularly the pipes beneath the roadways. The blockage subsequently builds up as rocks, sand and clay are caught in the foliage. This results in the diversion of the streams (that are, in any case, somewhat ephemeral), sometimes over the roadway, causing rapid erosion of the road, possibly the destruction of the embankments and the removal of the wooden-plank bridges. After destruction of the bridge, the stream may flow along the roadway

Figure 5. View of a typical narrow unfenced wooden road bridge under reconstruction near Malimono, Surigao del Norte, Philippines. The "Jeepney" we were in had to ford the swollen river, flash floods having swept away the former bridge. [© J F P Galvin]

Figure 6. Diverted section of a small river, now flowing along the unmetalled roadway, rather than in its former bed, south of Malimono, Surigao del Norte, Philippines. [© J F P Galvin]

itself (Figure 6), subsequently finding a new route to the sea. In these cases, the stream may be so deep after periods of even slight rainfall, that motoring through them, even in the typically sturdy "Jeepneys", becomes impossible.

It is clear that, even when money is provided to improve this road, the only one connecting the barangays of the west coast of the peninsula to the provincial city of Surigao in the north, careful planning will be needed to ensure that the road is not easily damaged. The use of relatively narrow concrete pipes is clearly inadequate to deal with flash flooding. The wooden-plank bridges are easily washed away and their comparatively remote setting makes them difficult to replace easily. The ephemeral nature of the rivers themselves makes them difficult to bridge permanently and comparatively large investment will be needed to ensure that maximum flows do not flood, or wash away the road. This will be ever more important as development allows the road to be metalled.

Conclusion

Flash floods are a major hazard to coastal populations in the mountainous districts of the world, as well as occasionally those who live in the less spectacular topography of areas affected by long periods of heavy rain.

Although classically the outwash fans of flash floods in desert areas have received much attention and are a hazard to desert populations, it is in the more populous regions of the humid tropics and middle latitudes that their effects can be most devastating.

The flash floods of more than 50 years ago in Lynmouth, Devon caused significant loss of life, not necessarily seen in the western coastal plain of Surigao del Norte. Although heavy rain is commonplace in the Philippines and swollen rivers are a constant threat, the disruption caused by flash floods in some rural areas can be severe. These areas are already affected by typhoons, earthquakes and volcanism. Flash flooding is a frequent addition to disruption in this area, causing damage to infrastructure and communications, as well as occasionally homes and businesses.

Even economic development of the region may not necessarily benefit the people affected by this perennial hazard, unless sensible investment and suitable countermeasures are undertaken.

Acknowledgements

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References

Bartholomew J, 1953, *The advanced atlas of modern geography, 3rd edition*. Meikeljohn and Son Ltd., London.

Brown G, 1990, S339 *Understanding the continents, Block 1A: What is the lithosphere?* Open University Press, Milton Keynes.

Delderfield E R, 1953, *The Lynmouth flood disaster,* J Atkins & J Etherton, Exton.

Highland L M, Ellen S D, Christian S B & Brown W M, 1997, *Debris-flow hazards in the United States. U.S. Geological Survey Fact Sheet 176-97* obtained at http://geohazards.cr.usgs.gov/factsheets/html_files/debrisflow/fs176-97.html

McGinnigle J B, 2002, The 1952 Lynmouth floods revisited, *Weather,* **57**, 235-242.

Open University, 1983: *S236 Geology, Block 4: Surface processes.* OU Press, Milton Keynes.

Open University, 1989a: *S330 Oceanography: The ocean basins: their structure and evolution*. Pergamon, Oxford.

Open University, 1989b: *S330 Oceanography: Waves, tides and shallow-water processes.* Pergamon, Oxford.

Author

Jim Galvin works as the National Meteorological Service Customer Manager at the Met Office headquarters, Bracknell. He is now in his 24th year with the Met Office. His first degree with the Open University was based on Earth Sciences and he graduated with a 2:1 in 1997. He was awarded an MSc in Applied Meteorology by the University of Reading in 2000. He is the Editor of the NWP Gazette and Honorary Photographic Editor of the Royal Meteorological Society journal Weather. His interests include geology, music and photography.

Book reviews

Surviving Galeras by Stanley Williams, 2001, Little, Brown & Co., 270 pages, £16.99 hardback, ISBN 0316855707.

No Apparent Danger by Victoria Bruce, 2001, Harper Collins, New York, 239 pages, $26.00 hardback, ISBN 0060199202.

I am taking the slightly unusual step of reviewing these two books together since both tell of the events leading up to and following the eruption on January 14th 1993 of Galeras, hitherto considered a 'well behaved' but active Columbian volcano. Another reason for combining the reviews is that the book by Victoria Bruce refers to Stanley Williams' book and is not a little critical of his part in the tragic events. Both books have as their main underlying theme the quest to describe and understand the chemical and physical symptoms that precede volcanic eruptions.

The books have a similar narrative style which is that of the thriller and true to that genre Bruce's book contains both heroines and unreconstructed males. The books are intended for a general readership and provide an overview and some explanation of the physical and chemical techniques used to investigate the workings of volcanoes.

The first part of Bruce's book deals with an historical account of volcanism, seismology and politics in Columbia, culminating in the catastrophic eruption of Nevada del Ruiz, a volcano 350 miles to the north of Galeras. Bruce emphasises the importance of a particular seismic signal known as a 'tornillo' which had been shown by the Swiss scientist Bernard Chouet to precede certain volcanic eruptions, whereas Williams was convinced that the composition of gases issuing from fumaroles was crucial in predicting such events.

With the exception of the differing emphasis on the relative importance of chemical and physical indicators, the authors' accounts of the events leading up to the Galeras eruption are similar. However the agendas pursued in describing the days that follow the eruption soon diverge. Williams refers warmly to the camaraderie of the volcanologists involved and tells of his subsequent recovery from his injuries and of later visits to some of the relatives of those killed on the volcano. Bruce seriously questions the wisdom of taking a party of scientists into the crater when seismic activity had been detected in the preceding days, particularly the occurrence of the long period, tapering screwlike traces of tornillos. Bruce also makes much of Williams' macho attitude in working with active volcanoes and the singular lack of safety equipment and arrangements. All of which in different circumstances and culture would be fair comment. But the people concerned were not inexperienced students (with the exception of the three sightseers for whom Williams could hardly be responsible) and those of us who have seen and listened to the video and audio cassettes for S267 will recognise something of the volcanologists' culture. For example the images of Hazel Rymer and Geoff Brown clad only in walking gear with no sign of hard hats sitting near the edge of the glowing crater of Mt Etna. Also Hazel Rymer bare headed and in shorts hiking up the side of a volcano in Costa Rica and remarking that the boulders she was passing had been ejected only about two hours before. They will also remember Geoff Brown's description of being caught out by an unexpected eruption of Etna, with metre sized bombs splattering around him and his comment that this is a risk that members of the profession have to accept.

It is easy to be wise after the event and one is left to wonder whether the experienced volcanologists who sadly became victims of the Galeras eruption would have been persuaded by remonstrations on safety by Stanley Williams, should he have made them at the time.

According to Bruce and some others she interviewed, the long period seismographic warnings were crucial and should have been reported and not ignored. However it appears that the previous success of the tornillo events in predicting imminent eruptions had not been peer reviewed and published, and may have been viewed by those volcanologists who were aware of them as one of the several potential, but as yet unproven, physical and chemical predictors of volcanic activity.

I feel if Bruce had been content to leave the matter there we could all have made up our own minds on the question of safety. However the final chapters of her book refer in a rather overkill manner to other matters, including alleged comments by Williams that he was the only survivor of the eruption and also a publication which made an apparently unfair claim for his research students in recognising the tornillo signal as a prelude to eruptions.

Both books are a good read and difficult to put down and perhaps because of the polarised views of the authors a certain piquancy is added.

Tony Milward FGS, continuing ES student

Ammonite Forest

Rob Heslop

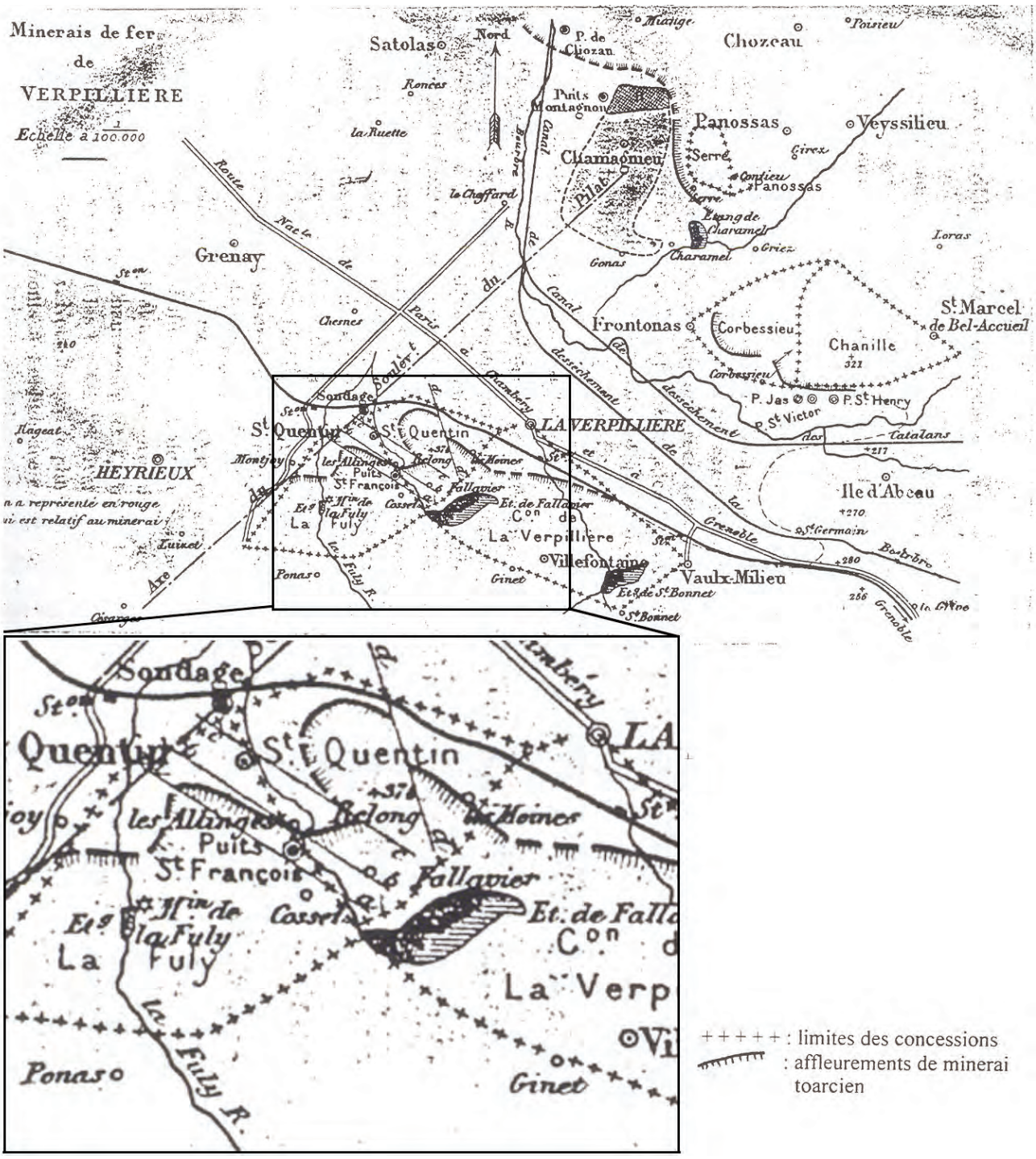

Figure 1. Les mines de fer de l'Isère (d'après Chansell 1885).

On the great red sunset wispy clouds slowly fade, leaving a completely clear sky. From where I stand, I see the rugged silhouette of the distant Monts de Lyonnais. The day dies and the skies turn green, then blue, and onto dark night. This is freezing open skied mid-winter, and strangely somehow I feel the time is just right, despite the cold, to return to ... Ammonite Forest.

The mornings' icy roads carry little traffic. I speed past an old blue, trundling truck, laden with logs, cross the county line of department number 38 known as l'Isère, and approach St. Quentin Fallavier village (Figure 1).

The landscape stands motionless and silent. Only the odd clump of dark green mistletoe, thriving on old twisted oak branches, show any colour. Otherwise all is held in frost; the trees, woods, fences and fields. I notice two or three buzzards, one after the other, standing on fence posts, pylon wires and branches. These large birds are starving and cold, winter is a testing time for them.

Figure 2. Watercolour of the medieval castle surrounded by the Ammonite Forest.

A little further on I see another, biding time on a wooden gate. Its sharp eyes stare, startled, from a brown rounded head. Could I be the first morning visitor on this frosty country lane?

Then, from around a bend I see it. A medieval castle, upon the summit of a wooded hill (Figure 2); these are the woods of Ammonite Forest. I drive through St. Quentin Fallavier, a typical, small French village with its cafès and boulangeries. At the cemetery, I turn right, and after a few kilometres park the motor at the heart of the forest (also called Mont Relong).

Taking a small rucksack I head down a winding, leafy track. Icy, copper oak leaves cover the way underfoot, the going down is steep and I slide and stumble as the frozen humus gives to movement.

During the early 19th century this place was a thriving iron mining area. The shafts, air-ducts and tunnels are under these woods and lands. The whole of Ammonite Forest is riddled with them. Rich red iron ore was extracted underground from the Aalenian and Toarcian strata, (Jurassic, 173Ma). The mines closed and were abandoned 120 years ago. There were other iron ore exploitations at nearby Verpillière and Hières sur Amby, and these too have been discarded. There are no buildings left, no rails; suddenly, man just left.

Simultaneously, in 1860, large gangs of miners sunk the various shafts in these three regions. The iron ore was dragged out and pounded; despite the massive initial investment the mines were abandoned after only 20 years of extraction, as the seams covered a much smaller surface area than originally suspected.

This is because the remainder of the Aalenian/Toarcian strata are irregular due to excessive geological activity; mostly from the Belledonne (westerly alps) fault-line, less than 60km away, and the heaving of the mountainous Pilat Park (metamorphic), 30km to the south east. There is much activity at Belledonne; two vast tracts of land oppose and push, shove and bicker as the rest of the planet spins! From time to time they crush, grind and splinter, causing an unimaginable explosive shudder. Consequently, the alps swell higher, the local geography ripples, underground mines creak, and Ammonite forest sways.

Deep in the silent woods, I find a mine 'dip'. There is a pitch black hole leading down into the abyss. How far underground does it go? Sinister and forbidding, a warm draft of air and steam bellows from the small duct, warmer temperatures from a darker world.

The last time I came here was with a friend called 'Callioux'. Together, well kitted out in caving garb such as big boots, hard hats, ropes and lamps, we ventured into one such duct. Crouching to get along, wading through cloggy mud, constantly banging and bruising elbows and knees upon low rocky vaults, jutting corners and scattered boulders, we extracted large slabs from the floors, and slowly filled up the snow sledge we had dragged down with us. Through each turn of our heads a razor shaft beam of light cut through hell's complete and utter darkness. Every mention of a word cut through hell's complete and utter silence.

We spent more than four hours underground and saw, to our amazement, thousands, and thousands of ammonites! *Hildoceras, Pleydellias, Grammoceras*; many different species from the tropical Toarcian seas. All glued vertically or horizontally on the floors, ceilings, walls and loose rocks. Everywhere, thousands of fabulous ammonites. But perhaps remains of ichthyosaur and plesiosaur too. What an incredible adventure! A photograph of underwater, sedimentary death. Man obviously never lived during the Jurassic times, but on that remarkable day, man almost did!

Coming back to the surface was painful. The long crawl was slow due to our hefty, heavy sledge, we had greedily over-loaded it. Pulling and pushing, banging once again those bruised elbows; constantly slithering on that mud, half entangled on the ropes attached to the cranking sledge; we agonizingly got out.

Finally back in the forest to daylight, we were greeted, not by a horde of people, lights, or TV crews, not to the hero's welcome of a Great First in time travel, but by rain, winters gloom, soggy leaves, and silence.

We were thrilled, however, by our adventure, and busied ourselves separating our 'loot' in two. Large fossil filled slabs were loaded into our motors. We had 'earned' about 60kg each.

A few days after, I engrossed myself in carving the blocks, enhancing ammonites, leaving them imprisoned, digging out unwanted sediments, and in the process of doing so, revealing yet more fossils underneath. One such block is exceptional; six various shells curl around each other, while 3 or 4 remain entrenched on the edges of this 10kg slab. A museum piece.

The 'Toars-regions' were the tropical lagoons, small islands, and sand banks which in part, formed the dinosaur-ridden areas of the great continent of Armorica.

Over time, hills and mountains eroded, and iron-rich sediments and silts were dragged down to the ever decreasing lagoons … The ammonite masses faced suffocation and death in a changing, drying sea.

Continuing once more through the woods on this frosty morning, I pass various fossil sites, here and there, left and right. I always try to leave the beaten track, and find a new 'site'. Today I settle for a clearing, surrounded by oak and hornbeam.

Digging through humus and frozen, sweet smelling earth, I rapidly find the red Toarcian sediments, and amongst the 'red'; AMMONITES! Sometimes imprisoned in a rock, but mostly individual, palm-sized, ammonites (Figure 3). (Ichthyosaur vertebrae are fairly common.)

Using a small 'fold-up' spade, and a geo-hammer from my rucksack, I spent a while, digging alone in that freezing wood and managed to find a few different species of ammonite, all in good condition.

After backfilling the dig, I made my way to the motor.

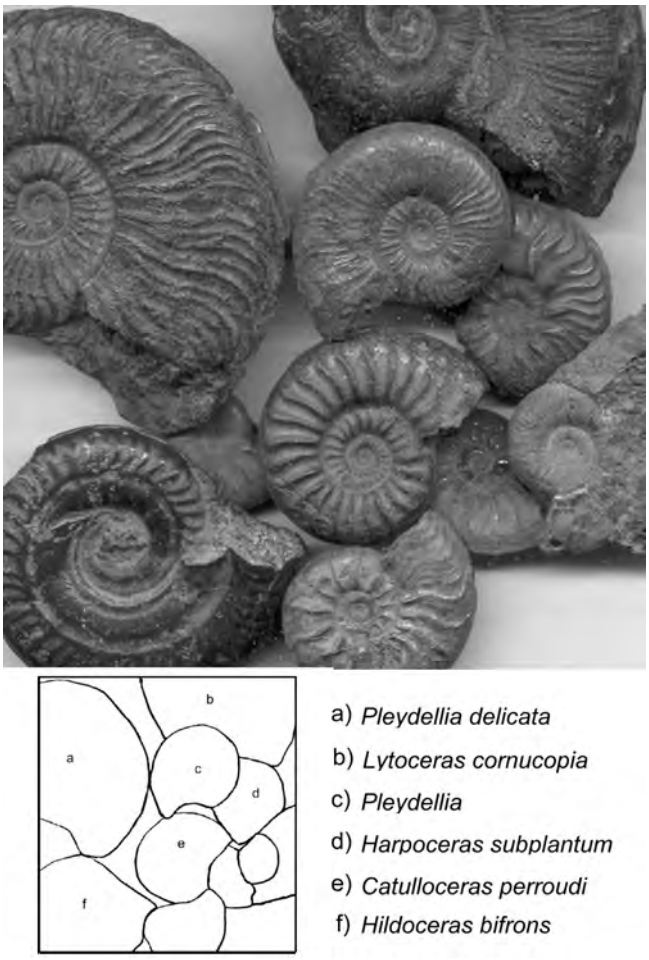

Figure 3. Toarcian/Aalenian ammonites.

On this stark winter's day, it is hard to believe that this place was once a tropical, shallow ocean, teeming with creatures and molluscs that no longer are.

The various 'events' lived upon a landscape will always show, sometimes faintly. This is the fascination of landscape, whether it be geology, archaeology, or palaeontology.

Nature, ever-present, shows the scars of experience, of trouble, struggle, upheaval and toil. It is fantastic to feel and unravel the landscape, and read amongst the roots. Through the recorded time span of this spot I hear a distant, ever-so-faint whisper.

Finally, facts from the forest:

- The Lyonnais geologist, named Tardy, first identified the areas for iron exploitation in 1841.
- Many shafts and galleries were dug under the forest. It was recorded that in 1862, the 55 miners working here extracted 1000 tonnes of iron per month.
- The Toarcian strata were rarely thicker than 50cm; the iron oxide present was between 50 and 65 %.
- The red colour of the sediments is due to red haematite.
- Most of the stratigraphic sequence was interpreted by a French naturalist named Durmontier. He originally called the Toarcian the 'Hildoceras Zone', as the *Hildoceras* ammonites are extremely numerous, and can only be found in the Toarcian.
- New species and varieties of ammonites are still being discovered from this remarkable site; so far 130 species have been listed.
- Fossils can be found on the forest floors as all debris and waste from the mines were scattered and discarded.

Reference

Chansell J, 1885, appearing in *Geologie et Palaeontologie du Carrieres Lafarge* by the Geology Groupe de Belmont and G Gastineau, 1979.

Rulleau L, (Catalogue de reference) 2000, *Geologie et palaeontologie des anciennes mines de fer de l'Isere, Toarciers et Aalenian*.

Author

Originally from Northumberland Rob left the UK at the age of 19 and has been in Lyon for 16 years or so. He lives with Anne, a musician and has two children, Laura and Kevin, and one unborn on the way, for May 2003! He works as a postman. He loves the great outdoors, and spends much time 'exploring', painting landscapes, and writing short natural history articles. He reads a great deal on topics such as palaeontolgy, British prehistory, the French Gallo-Roman period, archaeology, botany, wilderness and landscape.He enjoys the new science of exobiology, and generally all concerning the ongoing quest towards understanding that strange and enigmatic Life-spark!

Book review

Particulate Gravity Currents, Ed. W.D. McCaffrey, B.C. Keller and J. Peakall, 2001, Blackwell Science, 302pp, £55 (paperback) ISBN 0632059214.

This collection of papers has been produced as a result of the 1998 conference 'Sediment transport and deposition by particulate gravity currents', hosted by the School of Earth Sciences, Leeds University. Within its pages are some twenty papers which, to quote from the preface, represent a cross section of investigations from 'turbity currents in oceans, lakes and reservoirs to pyroclastic density currents and avalanches; debris flows and lahars; powder snow avalanches; effluent dispersal and ancient gravity current deposits.'

As such, it is clearly not bedtime reading, but a learned investigation into many aspects of turbidity flows. It is split into four sections, 'Theoretical and numerical approaches', 'Combined theoretical and experimental approaches', 'Experimental approaches' and 'Field based approaches', so that relevant papers are grouped together, for ease of reference. A logical sequence of papers is started by a paper covering the 'Mechanics and simulation of snow avalanches, pyroclastic flows and debris flows', in which the author explains features of the various flow types, proposing a unified theory for debris flow, while a subsequent paper applies the general model to 'An analysis of the debris flow disaster in the Harihara river Basin'. As might be expected, these theoretical articles contain a fair bit of maths, and are somewhat specialized, running through such subjects as 'Theoretical study on breaking waves on antidunes' and 'Ping-pong ball avalanche experiments'. The maths does not go away in the succeeding sections, however, as we move by stages through to experimental and finally field based investigations. In the 'combined theoretical and experimental' section was the paper 'Dam-break induced debris flow', which I found particularly interesting. The field-based section held considerable practical information, and much of interest, in particular within those papers examining various aspects of volcaniclastic turbidity flows.

Not one for the bedside, then, but an invaluable summary and aid to further research in this field, which would be a welcome addition to the geological section of any library.

Graham Arrondelle, BA Hons, continuing ES student

Ramblings of a Geology Enthusiast: Ease Gill, Yorkshire Dales

Alan Stollery

Ease Gill is a study of potholes, gorges and caves. I have been curious about this part of the Yorkshire Dales for some time and eventually my curiosity got the better of me so one day I decided to have a look.

In order to find this somewhat isolated place I drove to Kirkby Lonsdale (SD6178), approaching from the south-east and, just before the bridge over the river Lune, turned right along the A683 towards Sedbergh. Just before the village of Casterton I turned right and found myself on a quiet road which climbed out of the Lune valley and after a few miles came to Bull Pot Farm (SD 663 814). The farm is no longer used as such but is now a caving centre and is where I parked my car.

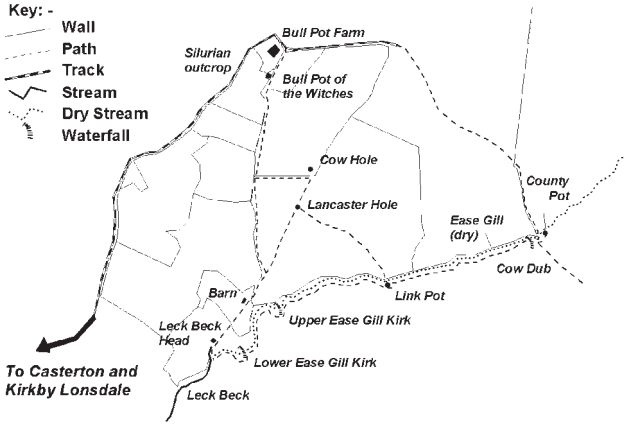

Figure 1. Map of the area. (Map by Don Cameron after an original sketch by Alan Stollery.)

There is a track from the farm (Figure 1) which leads down the open valley and after 200m or so a large pothole is seen on the right. This pothole is Bull Pot of the Witches which I treated with great respect ... it is potentially very dangerous.

I should mention that this region is on the boundary between Silurian rocks to the west and Lower Carboniferous rocks to the east. On the west side of the road I came across Silurian rocks which can be seen in small roadside excavations whilst to the east there are the limestones of the potholes and the farm. The road runs more or less along the junction of the two formations.

The limestone beds at Bull Pot are nearly horizontal. As I went farther along the path I noticed depressions and holes on the left of the path and also a lime kiln. The beds were showing a slight westerly dip. There were also slight oily seepages from decaying moorland vegetation. Soon a wall shoots off to the left and the path runs onto open moorland; I turned left and followed the wall to where it makes a right angle turn. On the other side of the wall at this point is a deep prominent pothole, namely Cow Hole. It is advisable to keep well away from its edges ... it is not a safe place to wander. The bedding is horizontal and there is a small limestone bridge across part of the pothole. Should anyone visit the pothole ON NO ACCOUNT TRY TO WALK OVER THE BRIDGE!

I now headed to the junction where the valley from my left joined a valley from my right and after walking a few metres came to

Figure 2. Entrance to Lancaster Hole.

exposed limestone outcrops amidst which is a rectangular concrete slab with a metal manhole cover in the middle (Figure 2). The cover leads down to Lancaster Hole. It must not be obstructed as it is one of the main ways into the Ease Gill cave system and if explorers find this exit blocked they would have to try to find the other entrances which would be very arduous for them. I should mention here that the Ease Gill cave system is one of the longest, if not the longest, cave system in Britain and covers well over sixteen miles of passages.

From Lancaster Hole I continued in the direction towards the valley junction but soon, after passing a disused barn, veered right into the right-hand valley aiming for about 100m up-valley of the junction. Around this region can be found a low flooded cave out of which flows a copious spring. The water flowing out of Leck Beck Head, as this place is called, is made up of all the water which flows through the Ease Gill caves, Lancaster Hole, the Lost John system and pretty much the whole of the underground water of the area (Figure 3).

Figure 3. Leck Beck Head rising.

The strata on the east side of the spring have an easterly dip of about15° whilst below the resurgence it is steeper at around 60°. Calcite veins run across the limestone.

My journey was now down the valley alongside the stream to the junction with the left-hand valley. This valley is a ravine and the limestone beds are steeply inclined with an easterly dip. I turned into the dry ravine walking, or more precisely stumbling, in the

Figure 4. Lower Ease Gill Kirk and cave.

upstream direction and in a matter of a few metres entered the ravine proper. Here I found a large pool blocking my progress. I tried to climb round it on the west side but found the way too treacherous. There is a path of sorts which climbs round the rim but this misses the part of the gorge I wanted to see so in the end I just waded through the pool and hoped that my boots and trousers would dry out during the rest of the walk.

I found myself in a kind of amphitheatre with a large dry waterfall blocking further progress. This is Lower Ease Gill Kirk (Figure 4). In the western wall there is a rather muddy cave. More interesting, however, is a cave in the eastern wall near the foot of the falls behind a large boulder. The cave is easily entered and an exit rises vertically to daylight some 5-6m above.

According to some books this vertical climb can easily be made; it comes out at the top of the fall. I found that with a torch in one hand, a camera round my neck and a rucksack on my back it was anything but easy. In any case the thought of slipping with the possible consequences of breaking a leg made the climb just not worth attempting so instead I retraced my steps and climbed out of the gorge up its eastern side then dropped back to the valley floor just beyond and above the dry fall.

Here gritstone pebbles and boulders make up much of the dry bed but the walls are well-bedded limestone. The limestone dips west at a moderate angle but there is a short section on the west wall where Silurian rocks are exposed in the lower part of the limestone wall (Figure 5). The inclined Silurian beds slope into the bed of the gorge where in about 30m they become lost from sight where a fault throws the limestone beds downwards on the waterfall end of the gorge. This seems to be the reason for the falls and Lower Ease Gill Kirk.

About 200m farther up the valley there is a second ravine and dry fall which is Upper Ease Gill Kirk (Figure 6). It is completely out

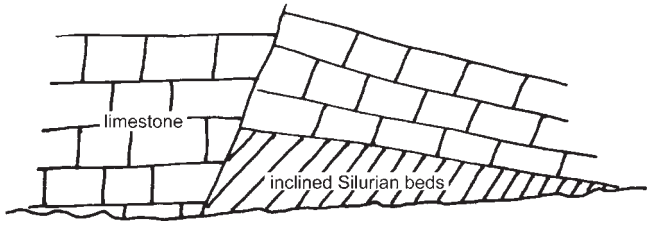

Figure 5. Silurian beds exposed in the west side of the ravine immediately upstream of Lower Ease Gill Kirk.

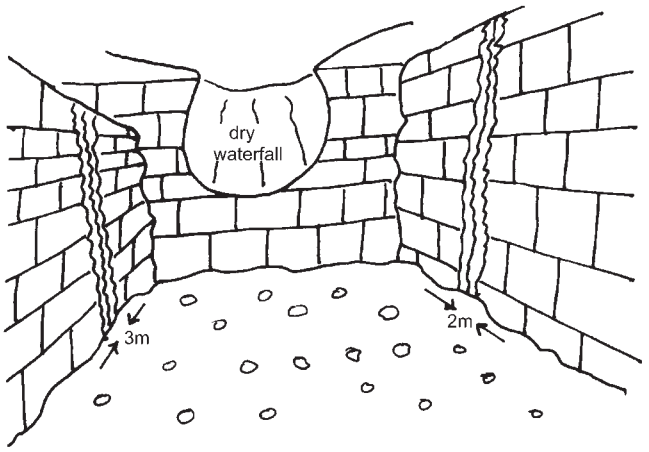

Figure 6. Fracture zone below the dry waterfall at Upper Ease Gill Kirk.

of the question to climb this fall so I made a detour round it in a similar manner to the lower fall. It is an interesting ravine to explore and the usual question arises, "why is it here?" The beds are horizontal but there is a section of rock wall at the foot of the fall with closely packed vertical jointing. The section is 3-4m wide. The jointing hints at a fault running across the valley so I am inclined to conclude that this second ravine and fall is possibly a consequence of faulting.

Up to this stage of the walk I had found no fossils (the fact that I had found no fossils does not mean they are not present!).

The beds above the Upper Kirk are horizontal and gritstone boulders abound. These are above the Silurian beds so I conclude they have come from the overlying Wensleydale/Upper Carboniferous deposits higher up the valley.

Figure 7. Dry stream bed near Cow Dub.

The next 500-1000m of the walk is along a dry river bed with one or two cave entrances into the Ease Gill System (Figure 7). I started to find fossils in the boulders along this stretch and they became more numerous as I went up the valley. Some were brachiopods about 5cm across, others were crinoids and a few existed as spirals up to 10cm across, (my fossil identification book indicated the gastropod *Staparaallus pentangulata*).

Eventually I came to another small narrow gorge, Cow Dub, but the path easily skirts round it. I had a look inside and found it was like looking into a cave with a waterfall at the far end (Figure 8). The

Figure 8. Cow Dub waterfall.

Figure 9. Sculptured bed above Cow Dub; the spider in the bath situation.

gorge was filled with a deep pool which prevented entry. The sculpturing of the rocks in the stream bed is quite impressive (Figure 9).

Once again the question arises, what has happened to cause this? Just before Cow Dub a band of north-easterly dipping limestone with a 60° dip runs across the stream bed but the Cow Dub ravine cuts through nearly horizontal beds of massive light grey limestone. Two shallow tributary valleys run down the eastern side of the hillside. These observations support the idea that, once again, a fault may be responsible for the existence of the ravine. Incidentally brachiopod and goniatite fossils are now plentiful in the boulders of the stream bed.

A stream flows above Cow Dub through a shallow gorge which has been sculptured smooth giving good erosional effects. I dropped into this gorge in order to have a good look at it and found that although it was easy to get down into it was a different proposition getting out … I could well appreciate the plight of a spider which has fallen into a bath!

Next there is a wall to climb over near a kind of concrete cattle bridge spanning the stream where the valley bends slightly. A few metres round the bend and on the left near the base of a cliff there is another manhole cover set in a concrete slab. This is County Pot which is the main way into the Ease Gill caverns.

Upstream of County Pot the valley becomes a low gorge and over the next few hundred metres lie most of the numerous entrances to the cave system. None can be entered without special equipment but some look as if it is easy to climb down into them but not back out. The stream now runs entirely on the surface and the various places where it sinks into its bed can be seen.

The valley now runs out onto the open moorland and the limestone is replaced by gritstones and shales. The route back to Bull Pot Farm was by returning to the concrete bridge below County Pot and retracing my steps down the dry stream bed as far as Link Pot.

On the right-hand side of the valley a stile leads onto a path running up the hillside to Lancaster Hole. From there was just a matter of retracing my steps back to the farm.

Recently I learnt that there have been problems with the landowner concerning rights of access. The entire walk is on private land but I understand that the walk I made confines itself to concessionary paths allowed to cavers in order to reach the caverns. As to whether these concessions still apply and are extended to walkers in general is not clear. All I can say is that this walk has been described in numerous publications, such as "Walking The Dales" by Mike Harding, "Wainwright In The Limestone Dales" by Alfred Wainwright and "Yorkshire Dales, Limestone Country" by Tony Waltham. For up-to-date information access:
http://www.redrosecpc.demon.co.uk/farm.htm
http://www.caving.org.uk/news/cases.html

Should anyone decide to follow this walk they should be aware of these problems and ON NO ACCOUNT return to the farm from County Pot by way of a path above the pothole across the moors. I have been led to understand that the cavers have agreed that this path is strictly out of bounds.

In conclusion I would like to add that a friend of mine once described to me how, on one of his cave outings, he was looking down into the dry Ease Gill valley when he saw a wall of water rushing down the valley and in a matter of minutes the dry valley changed into a raging torrent. There must have been a local heavy shower somewhere on the fells. It is a solemn reminder for anyone exploring caves in limestone country.

Author

After National Service in the RAF as a Radar Technician, Alan Stollery gained a London University External BSc in Chemistry and Physics. He spent 10 years in the textile industry before entering teaching. Alan was a teacher in charge of Physics at a Halifax Grammar School. After taking early retirement he took up geology as a serious hobby and gained a BA (Open) degree. The ramblings are made up from detailed notes taken whilst walking around the countryside.

Canyon Country: Presidential Field Trip led by Bob Spicer, 5-18 May 2002

Bob & Sheila Alderman, Jane Clarke, Caroline Deans, John Lamont, Peter Martin, Linda McArdell, Bob Morley, David Scarboro, Bob Spicer, Roy Sturmy, Len Wellington

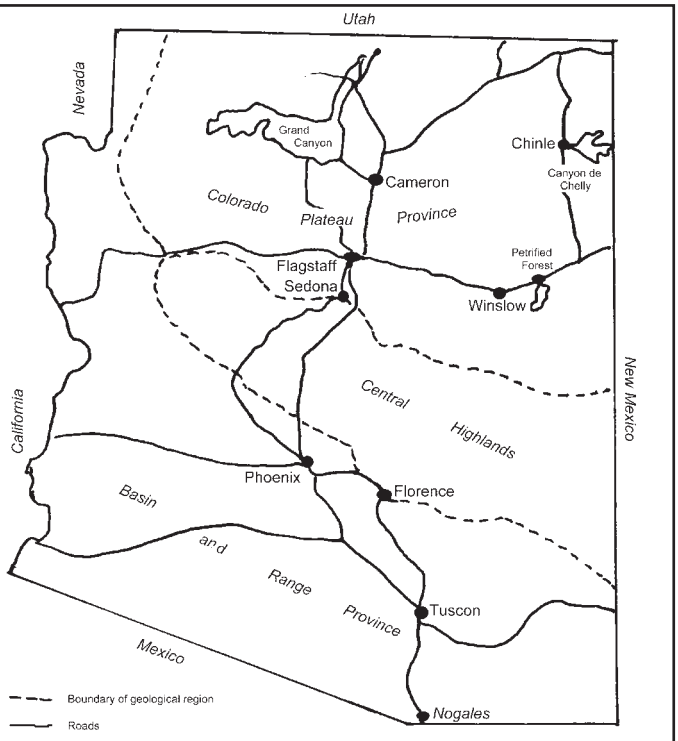

Figure 1. Map of Arizona geological provinces.

Geological context

Arizona can be divided into three main geological "provinces" or regions, defined on the basis of broad-scale topography (Figure 1). This trip encompassed all three beginning with the Basin and Range. As the name implies this province is made up of a series of basins separated by mountains. The whole region has undergone extensional tectonics with predominantly normal faulting creating a series of downfaulted blocks, the tops of which form the basin floors. This extension implies that the entire region has subsided from a previous high plateau and palaeobiological evidence suggests that in Tertiary times the region may have been considerably higher than the modern-day Colorado Plateau.

Most of the time was spent on the Colorado Plateau; mostly over 5000ft above sea level but dissected by downcutting rivers such as the Colorado. Erosion, much of it comparatively recent in geological terms, has formed a series of spectacular canyons and exposed rocks that represent most of the last 2 billion years of Earth history.

Tucson area and Biosphere 2

During the fortnight in Arizona and Utah we drove 2050 miles, so it was a great advantage to have Bob Spicer's local knowledge of the geology, Native American culture and the botany. Throughout the trip Bob was pointing out the link between the geology and the landscape and vegetation. We covered three areas in Arizona: the Basin and Range, Central Highlands and the Colorado Plateau. We soon learnt that the "pointy" mountains in that area tend to be volcanic. We were in the Basin and Range region.

Around Tucson, on the way to Biosphere 2, Bob was explaining about the vegetation in the desert. The area has experienced a drought lasting 120 years with twice-yearly rains. Water conservation is a big issue with 95% of any rainfall evaporating and only about 5% getting into the water table. Waste water is now used to irrigate places like golf courses. Irrigation is causing problems, however, because the water taken from deep boreholes contains accumulated salts and then the soil becomes saline because of the high rate of evaporation.

Bob talked about C_3, C_4 and CAM (Crassulacean acid metabolism) photosynthesis. For example oak trees are C_3 plants with stomata facilitating gas exchange. This is a disadvantage in desert areas due to water loss when the stomata are open during the day. In the high daytime temperatures ribulose 1.5-bisphosphate carboxylase-oxygenase (whew!) (RUBISCO), the enzyme that traps carbon dioxide as part of the photosynthetic process, also interacts with oxygen. The oxygen effectively competes with CO_2 for the active RUBISCO site and this 'poisons' the photosynthetic process. C4 plants such as maize and sugar cane have adapted to hot wet conditions. The stomata are open when transpiring but the CO_2 is fixed as a four carbon sugar, malate, before being acted upon by RUBISCO deep within the plant so oxygen is excluded from the process. This works well when the ratio of oxygen to carbon dioxide is high as it is now. When Tibet rose in the Tertiary atmospheric CO_2 fell and led to the evolution of C_4 photosynthesis.

CAM photosynthesis, the process carried out by most cacti, is an advantage in desert regions because with CAM the stomata only open at night when temperatures are lower and evaporation stress is reduced. The plants capture CO_2 at night and store it as malate, until the day when the stomata close. The stored malate acts as a substrate for photosynthesis which continues in the day, but sealed from the oxygen in the atmosphere.

The desert around Tucson is characterised by the giant Saguaro cactus as in the American Western movies, Cholla cacti including Teddy Bear, which is fluffy but certainly not cuddly and Jumping Chollas, which look like Brussels sprouts and reproduce vegetatively. The "sprouts" become attached to the coats of animals but after a while, when the animal has wandered away from the parent plant, they fall off and a new cactus results after the "sprout" has taken root. In southern Arizona plants have colonised from both the south (Mexico) and the West (California) so there is a wider range of plants more typical of a tropical desert even though the area is well to the north of the true tropics. The creosote bush smells like desert rain when crushed. The Ocatillo looks like dead twigs but this is a dormancy strategy. The plant drops its leaves in times of drought but grows them again when there is sufficient moisture. The Mesquite bush with a yellow catkin-type flower is drought resistant as is the Palo Verde, which sheds its leaves as a water conservation response but continues to photosynthesise through the green stems and trunk.

Biosphere 2 (Figure 2) was inspired and funded by Edward Varse who invested $100 million in the experiment to build a self-sustaining closed biosphere sufficient to sustain human life. The project started in 1984. Oxygen, carbon dioxide and water are

Figure 2. Some of the biomes at Biosphere 2.

needed with correct proportions of plants, insects, soil system, balanced moisture, cleaning and recycling. As the system is sealed the expansion and contraction of the air with changing temperatures also had to be addressed. The outcome was 3.15 acres enclosed by a glazed stainless steel spaceframe. Outside Biosphere 2, but connected by sealed underground tunnels, are two geodesic domes called "lungs" containing giant rubber membranes which lift to accommodate the expanding air as temperatures in the glass biomes increase and descend as the air cools. Within the biomes 2000 species of plants and animals (not counting microbes) were introduced. The biomes simulated the environmental conditions of a rainforest, marsh, savannah, desert and ocean. There was also an area for intensive agriculture and a human habitat. From 1991 to 1994 crews of up to eight people lived successfully in Biosphere 2, from six months to two years. However, the experiment showed that the glass was filtering out the ultraviolet, which is essential for some chemical reactions. Also CO_2 was building up and became too high for the humans to remain safely enclosed. The system was not quite balanced with one of the factors appearing to be the weathering of the concrete in the structure. Now some of the Biomes are open to the public so are no longer sealed systems. Other areas are sealed for experimental use to look at growth in defined conditions. The desert area is being transformed into a shrubby woodland because the high humidities spilling over from the rainforest area have affected the plant composition. The view of the ocean through the glass is indistinct because of calcium carbonate build up, which does not affect the marine life. Biosphere 2 is now part of Columbia University and is used as a non-profit research and education centre.

Tucson to Flagstaff

Making our way north along Interstates 10 and 17 we encountered all of the three geological provinces of Arizona: Basin and Range, Central Highlands and the Colorado Plateau, the first of which will be well known from OU geology courses. An arid climate ensured that geology was the landscape, unlike in the UK where we often have to make the best of isolated outcrops.

There were three surprises: first, the vastness of the landscape, second, the evidence of Tertiary and Recent volcanism particularly on the Colorado Plateau and third, Bob Spicer's encyclopaedic knowledge which extended to botany and anthropology. Consequently, in addition to the geology we enjoyed a fascinating insight into the various types of photosynthesis that enables specialised plants to survive in the desert. We also learned how the first settlers reached North America via the Bering Straits land bridge and thus shared some of their genetic characteristics with the Chukchi of NE Asia and the Inuit of Northern Canada, including a difficulty to metabolise alcohol; a fact which puts a new light on Wild West tales of gun running and liquor trading with the Indian tribes.

Figure 3. Picacho Peak.

But back to geology. Between Tucson and Phoenix we crossed a number of very large sedimentary basins loosely divided by NW–SE trending volcanic formations or remnant mountain ranges reduced to metamorphic core complexes. Just north of Tucson we spotted Kitt Peak Observatory on a distant formation. Alongside the highway we were able to take a closer look at Picacho Peak which appeared like a volcanic neck from a distance (Figure 3). This edifice turned out to be formed from rotated lava beds associated with anomalous Precambrian granite, a feature interpreted as material which had splintered off the magma chamber or conduit when the lava was erupted in Tertiary times. The rotation of the lava flow is consistent with modern interpretation of the regional geology of the Basin and Range. Although not entirely free from doubt this envisages the spreading and sinking of a once high-level Tibetan-type plateau.

The Quaternary basin sediments are up to 10,000 feet thick (the US seems reluctant to go metric!) and are laid on an ancient topography. The gradual withdrawal of groundwater has lowered the water table and the structural integrity of the sediments. The result is that fissures have opened up at stress points over buried ridges and cliff edges where variations in sediment thickness leads to differential compaction.

North of Phoenix the higher ground becomes more organised. The surface geology gets older with Tertiary and Quaternary sediments giving way to Precambrian granites and the metamorphic rocks of the Central Highlands. As we go northwards these are increasingly covered by Tertiary and Recent lava flows, particularly noticeable in road cuttings, where baked margins were often prominent. This lava-strewn landscape, clothed by sparse grass, continued over the summit plateau.

The next significant geological feature was the Verde Fault, strictly a fault zone. It forms the southern boundary of the Verde Valley, a down-faulted block that is surfaced by the Verde Formation, a series of Tertiary calcareous lacustrine sediments, about 3,000 feet deep. These were deposited as rivers draining to the south were dammed by the faulting. The valley forms a natural divide between the Central Highlands and the Colorado Plateau, although the valley itself is part of the Central Highlands. The northern boundary of the Verde Valley is known as the Mogollon Rim. This is an erosional feature rather than a fault, interpreted as resulting from the downcutting of a river running parallel to, but somewhat earlier than, the faulting to the south. Slump structures were noted, evidencing the undermining of the Mogollon Rim.

Unfortunately, we did not have time to visit the Montezuma Castle National Monument where prehistoric cliff dwellings are built into cliffs of the Verde Formation revealing an apparently cyclical depositional environment. Progressing northwards across the Mogollon Rim we passed through Pleistocene lake sediments that have yielded remains of Mastodon and other animals. These gave way to extensive Tertiary lava flows with occasional baked palaeosols overlying Permian limestones, shales and sandstones in successions that are in evidence throughout the Colorado Plateau and spectacularly exposed in the Grand Canyon.

As we approached Sedona we had our first glimpse of the red sandstone mesas so beloved of Westerns. The initial sighting through the front of the bus was a magic moment of the trip. We were soon enjoying our first photo opportunity at Bell Rock, a few miles south of Sedona.

These mesas, spires and pinnacles reflect the dissected edge of the plateau and their colourful appearance is attributable to the contrasting types of rocks in layer cake succession. They are mainly of Permian age, comprising variously shales, fluvial and desert sandstones, limestones and occasional volcanics.

At Sedona we were faced with a conundrum. The red apparent desert Coconino Sandstone did not show any large scale cross bedding, whereas this was present in the overlying buff sandstone. This was interpreted as being due to the leaching of iron from the Coconino (buff) into the shales of the Supai Group beneath where oxidisation had taken place in the arid climate.

Continuing towards Flagstaff we travelled through Oak Creek Canyon. The river follows a fault line and the sides of this canyon are asymmetric. On one side Kaibab limestone overlies Toroweap and Coconino sandstones and Supai and Hermit shales, typical of the Colorado Plateau. The other side is dominated by lava flows with prominent columnar jointing, dykes and baked margins resting on talus.

Topping the 1,500 foot climb out of the northern end of Oak Creek Canyon we completed the last few miles into Flagstaff. At an altitude of about 6,500 feet we had at last reached the Plateau. To the north of the town the volcanic San Francisco Mountains could be seen.

Barringer Meteor Crater

Tuesday morning saw us cruising east out of Flagstaff on the legendary Route 66, getting our kicks as we travelled over the 'good ol'' but rather flat and boring Permian Kaibab limestone, punctured by a few fairly recent volcanics which had managed to punch their way up through the thick raft of crust which is the Colorado Plateau. After a while the pale Kaibab disappears below the red but still featureless (Triassic) Moenkopi which we had seen looking so spectacular in section in the cliffs the day before. Nothing to make you think there is anything special here but for those who knew what to look out for there was a low rough-edged structure rising a little above the plain about 10 miles away to the south. Not so monotonous that day 50,000 years ago when 300,000 tons of nickel iron, 50m across, came in from the north-east to hit the spot at 40,000mph with an explosive force 1,300 times that of the atomic bomb dropped on Hiroshima. So was formed the crater whose worn down lip we were looking at (Figure 4).

The crater is a hemispherical bowl about 1km across and 210m deep. The bedding of the Kaibab limestone is clear in the upper parts of the wall, broken and tilted away from the centre by the effect of the impact. The impact penetrated and overturned the Kaibab so above it is the red-brown of the Moenkopi folded over and topped by paler debris of more Kaibab to rise 10m or so above ground level (Figure 5). There was less ejecta than I had expected from S281 videos, perhaps it had worn away as the guidebook says 175 million tons were spread over a mile all around. The slopes of the crater are covered by debris but fixed telescopes are trained on features of interest: a thrust fault from the blast on the south rim, limestone blocks the size of a house perched on the rim, old mine buildings on the floor. More shattered rock lies below to a depth as great again as the visible crater; the shockwaves broke up a further two formations, through the Toroweap and down into the Coconino sandstone. There is much more detail to be seen here than at the older (but very much bigger) Ries crater at Nordlingen in Austria and many splash droplets of iron have been found in the area, but the impact does not seem to have been big enough to produce tektites. On the other hand the site is quite different from Henbury in Central Australia where there is a group of very much smaller craters, some formed by explosion, others by impact; you can actually handle the largest bit of meteorite in Alice Springs museum.

In the 19th century there were two conflicting theories as to how the crater had been formed: one was meteor impact, the other was an explosion of superheated steam caused by the volcanics we had seen earlier. G K Gilbert, then chief geologist of the US Geological Survey, preferred the latter explanation, reckoning that a meteor would have had to be almost as big as the crater and there was not enough iron around for that; tests with a compass had told him there were no large hidden masses of iron, and it is likely that he did not have enough knowledge of physics to estimate the velocity and mass, and hence the kinetic energy, of the incoming meteorite. Ten years later Daniel Barringer heard of the crater and the

Figure 4. Barringer Crater

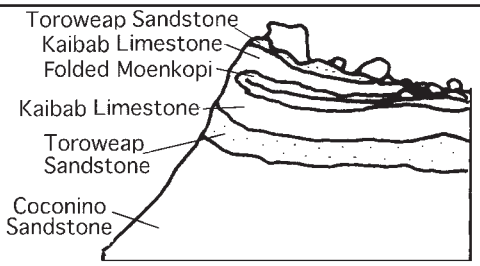

Figure 5. Sketch of cross-section of Barringer Crater.

small balls of iron randomly mixed with rocks of the crater rim. He was a successful mining engineer and reasoned that this could only have been caused by an iron meteorite and that, in spite of Gilbert's work, most of it had to be buried, probably under the crater floor. On this basis, and without visiting the crater, he formed a company to exploit the iron and secured mining permits. Over the next 27 years Barringer and his associates spent the equivalent of $10 million with no returns. However his name lives on and he did convince the scientific community that the impact theory was correct.

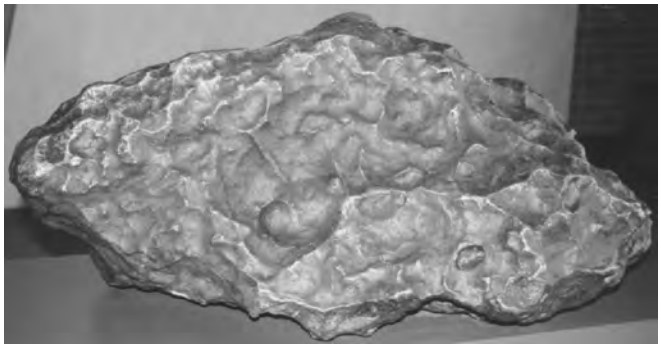
Figure 6. The inscription reads, "The Holsinger Meteorite is the largest discovered fragment of the 150ft (45m) meteor that created Meteor Crater". (70-80cm across).

There is an excellent museum at the site and as well as the spectacular specimens of fragments of the meteorite (Figure 6) there are fine illustrations and examples of modern scientific evidence for the origin of the crater: shatter cones (an inch to two feet long and which can only be created by sudden intense pressure), very shocked quartz (coesite) alongside ordinary quartz, magnified so that the difference can be seen, and "carbonados", microscopic black diamonds formed from small concentrations of graphite by the impact, which have been found particularly at nearby Canyon Diablo (similar ones have been found at the Ries crater). There was also a simulation machine where you could choose your own meteorite/asteroid for size, density, velocity and angle of approach and see what kind of crater it produced. The display states that Apollo astronauts used the crater for training as it has a similar shape to those on the moon. Gene Shoemaker correctly calculated the size of the impactor based on his work on craters from atomic bomb explosions.

It would have been interesting to take the tour round the rim (though the altitude of the Colorado plateau took its toll on us after even a quiet clamber around) and to spend more time in the museum, but Route 66 beckoned and we had to go on our way.

The Petrified Forest

From Meteor Crater we drove west on I-40 to Winslow, AZ, and from Winslow to Holbrook, a distance of about 60 miles. The rocks to either side of the road were flat-lying strata of the Moenkopi Formation, composed of sands and silts deposited on a floodplain in early Triassic times. The Moenkopi was only a thin veneer on the top of a flat landscape and was not well exposed except in occasional roadcuts and small mesas. However, as we approached Holbrook larger mesas revealed the contact between the Moenkopi and the Chinle Formation of late Triassic age lying on top.

At the top of the Moenkopi is an erosion surface overlain by the Shinarump Conglomerate, a thin but striking bed that was clearly visible in the mesas even from a speeding coach. The gravels of the Shinarump were derived from mountains that existed to the northwest in Triassic times. Above the Shinarump were the multi-coloured sands and silts of the Chinle Formation. The Chinle is what we had come to see, as it is the unit that contains the famous Petrified Forest of Arizona.

The sands and silts of the Chinle were deposited by a meandering river system on a broad, flat floodplain. In Late Triassic times this region was in the tropics and lay near the eastern edge of the supercontinent of Pangea; the rivers of the Chinle floodplain emerged into the Tethys Ocean not far away to the east. The climate was dominated by the mega-monsoon, cross-equatorial flow that characterised Pangea, with pronounced wet and dry seasons.

The varied colours of the Chinle Formation reflect the variety of oxidation states of the sediments as they were deposited in thick sequences on the floodplain. The greys and greens reveal reducing conditions, and the pinks and reds oxidizing conditions. Uplift of the Colorado Plateau in Tertiary times caused erosion of the Chinle Formation in what is now Petrified Forest National Park, producing badlands where the land has been dissected into gullies and flats separating mesas in which the colourful beds of the Chinle are well exposed. Erosion has also uncovered the petrified "forest" in the form of thousands of logs that have weathered out of the sediments and now lie in profusion on the ground in some areas of the Park. Logs can also be seen tumbling down gullies and protruding from the sides of some of the mesas (Figure 7).

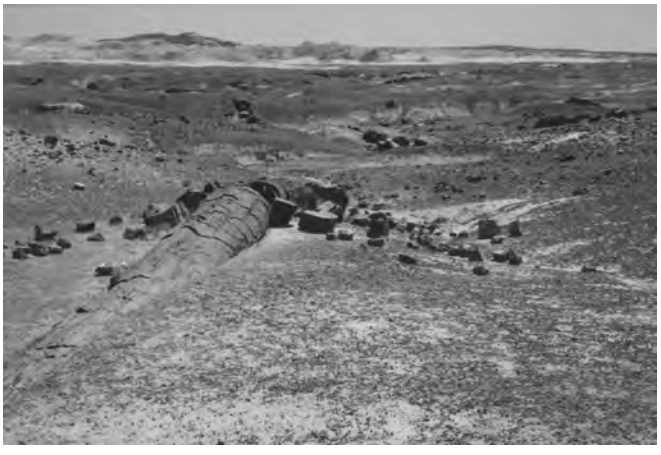
Figure 7. Scattered fossilised logs in the Petrified Forest.

The thousands of fossil logs that litter the landscape in places like the Crystal Forest (the name given one of the popular trails in the Park, Figure 8,) were transported to the area from uplands to the west and northwest, probably by raging streams during the mega-monsoon wet season. The trees of the Petrified "Forest", in other words, did not grow where they now lie. In some places logs have a preferred orientation, which is consistent with transport and

Figure 8. Crystal area of the Petrified Forest.

deposition by water. After burial the wood was replaced with silica derived from volcanic ash incorporated into the sediments.

Closer examination of logs revealed further details about their preservation. Logs broken and scattered randomly over the land surface were probably derived from layers of the Chinle that have now been removed by erosion, leaving the weathering-resistant silicified "wood" behind. In the Crystal Forest, however, many logs are still *in situ* and largely intact, and thus in older beds than the random and broken trunks scattered around them. Some of these *in situ* logs are huge, up to 20m or more in length. In some logs an examination with a hand lens revealed the tracheids and even individual cells, indicating that the wood was less silicified. Some logs have hollow centres where the pith rotted away before the silica, slowly penetrating through the trunk from the outside, was able to reach the centre.

Most of the logs belong to the genus *Araucarioxylon*, a gymnosperm related to the modern monkey-puzzle trees of South America (*Araucaria*). Our group had an opportunity to purchase beautiful sectioned and polished samples of fossil wood (all collected from outside the Park boundaries) from an emporium in Holbrook.

The floodplain on which the Chinle sediments were deposited was teeming with life, in spite of the fact that the logs of the "forest" did not grow where they are now found. Other plants on display in the Visitor Centre included abundant ferns and cycads (although these looked like *Bennititales,* an extinct group of Mesozoic plants that closely resembled cycads). Animal life included early dinosaurs such as the small predator *Coelophysis*, giant crocodile-like predators called phytosaurs, huge amphibians and fish.

Another highlight of our visit to the Petrified Forest was the Painted Desert, in the northern part of the Park. Here the sediments of the mesas and flats of the badlands reveal a brilliant kaleidoscope of colours. This feature of the Chinle Formation can also be seen where the Chinle outcrops east of the Grand Canyon, where the name Painted Desert is again applied to the multi-coloured badlands of that area hundreds of miles west of the Petrified Forest National Park.

The Heart of Indian Territory, Canyon de Chelly

We piled into the bus for our trip along the south Rim of Canyon de Chelly (pronounced "d'Shay"), all seemed well, the sun was shining with not a hint of clouds in the sky. As we walked to the viewpoint Bob regaled us with information about the various desert plants which could be seen on either side of the well maintained path, among which were included California Lilac, Live Oak and parasitic mistletoe on the pines. We then had our first view of this canyon.

The view is stunning, with vertical red cross-bedded sandstone walls up to 1,000ft high surrounding a valley centred on a line of green cottonwood trees following the water course.

Figure 9. Spider Rock in Canyon de Chelly.

Rising from the floor of the canyon is the dual spire of Spider Rock, 800ft of sandstone isolated from the canyon walls, the home, according to Navajo belief, of Spider Woman who taught humans the art of weaving (Figure 9).

At the top of the sandstones lies the Triassic Shinarump Conglomerate, the lowest member of the Chinle Formation, a hard, resistant, alluvial deposit containing quartzite pebbles, the heavier pebbles of which can be seen as close-packed desert pavement resulting from erosion of the calcium carbonate cement and winnowing of the finer sand grains; outcrops can be examined beside the path to the viewpoint. Below this lies the de Chelly sandstone, relatively pale red sandstone with massive cross-bedding with steep swooping laminae representing the remains of the dunes of the vast Permian desert of Pangea. The top surface of the sandstone represents the erosional surface of a 60Ma old unconformity with pre-Shinarump stream channels cut into the surface.

Between the fine sediments of the dunes lie horizontal erosion surfaces, allowing the cliffs to form the impressive overhangs under which the Indian settlements can be found.

At our next stop, the Sliding Rock viewpoint, we saw evidence of man. Hidden in the shadows of these overhangs are the remains of buildings, evidence of the native indians who used these canyons for food and shelter (Figure 10). These buildings are even more impressive from the White House overlook, where the structure known as the White House can be clearly seen in a ledge on the opposite canyon wall. The canyon can be accessed from this point by a trail leading from the rim to the canyon floor but we all decided to wait for an easier way in the afternoon!

These dwellings are dated to about 1200AD although people have lived in the canyon for over 10,000 years. The principal natives were the Anasazi (the "enemy ancestors" of the Navajo) who had descended from nomadic hunters travelling from north-east Asia via Alaska. These people started raising crops, mainly corn and beans, and lived in the caves and cliffs around the turn of the first millennium. By about 500 – 700AD they were known as the Basketmakers due to their prowess in this area. These peoples eventually established the pueblo culture which reached its peak around 1050 - 1300AD, when most of the dwellings in the canyon were built. Around 1300AD these tribes moved on, possibly as the

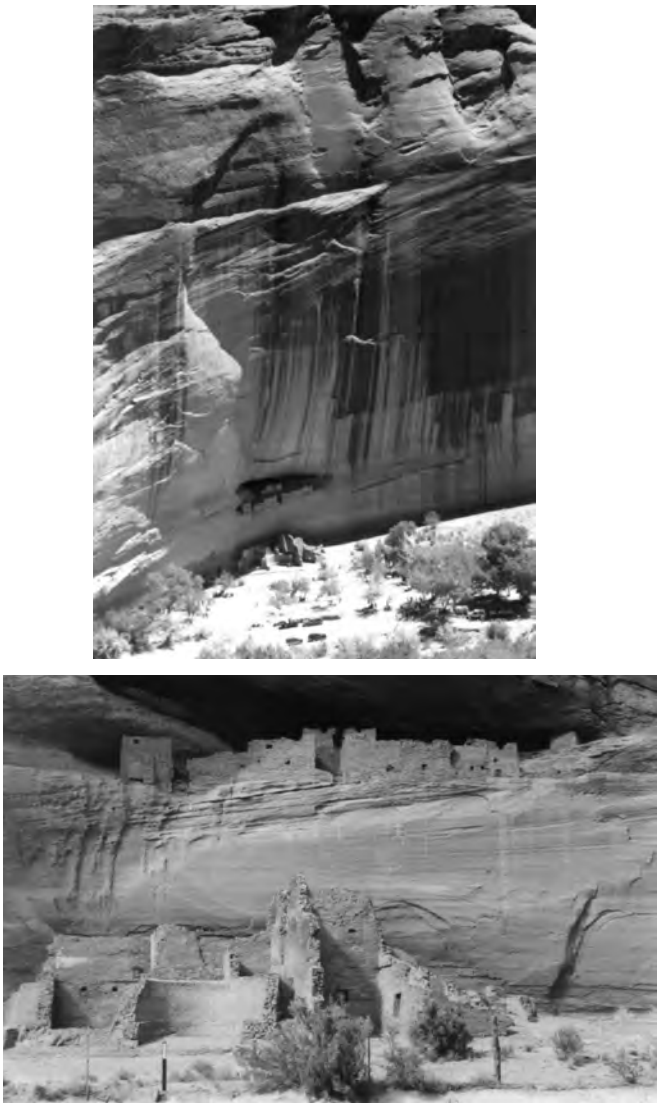

Figure 10. Anasazi ruins: the White House from the overlook (top) and from the canyon floor (bottom).

result of drought brought on by climate change. Apart from sporadic occupation by the Hopi it was not until 1700 that the Navajo began to reoccupy the canyons and have done so ever since despite efforts by the Spanish and American settlers to oust them.

From the canyon rim we adjourned to the Thunderbird Lodge, part of which contained one of the original trading posts in the area. After lunch we embarked on the next stage of our exploration of the canyon on the back of flatbed trucks converted into open top buses, more comfortable than they looked, but only just. Today there are around 130 Navajo clans around the canyon area where they still live and work. Our Navajo guide, Haral Dinisen, a native of the canyon, was able to give us a good account of the archaeology of the ruins in the canyon.

As we drove through sand drifts into the canyon the walls of red sandstone grow rapidly in height rising above the sparse vegetation of mainly cottonwood trees. At this level the scale of the cross-bedding is impressive as dune mounts on dune.

Our first main stop is the aptly named First Ruin, a dwelling, dating from between 600-1000AD, which would have housed a family or tribe in 15 to 20 rooms built round a circular room similar to the later Navajo hogan. Access to the house would have been by handholds and stairs, although it was suggested that the floor of the canyon may have been higher at that time, having been subsequently eroded by the seasonal flooding which still occurs. Indeed the Navajo only live in the canyon during the summer months, leaving with their cattle via the steep paths up the canyon walls when the annual rain begins.

Moving on to the Junction Ruins, at the junction of Canyon de Chelly and Canyon del Muerto, a red-tailed hawk was spotted circling above; just one of the abundant wildlife living in the canyons. According to Haral animals like bears and pumas can be found deep in the canyons well away from humans. We are told the Anasazi were a small people, only 4-5ft high who built small doorways to keep the heat in. Similarly the houses were all built on the north wall of the canyon to make use of the winter sun.

The canyon walls are covered by a dark, shiny stain of manganese and iron oxides known as 'desert varnish' which provided a ready canvas for the native inhabitants to leave their mark. At Ledge Ruins we see paintings of turkeys and sun and moon; all the ruins have hand marks which are identification signs. Not all the paintings are old: at Antelope Ruins we see Navajo drawings joining those of their ancestors and pictures of horseback riders represent an incursion by the Spanish who massacred the Navajo at the appropriately named Massacre Cave.

At Navajo Fortress rock we come across a less savoury aspect of American history for it was here that the Navajos fought a last stand against Kit Carson and his cavalry, leading to their subsequent removal from the canyon for several years before being allowed to return to what is now the modern day reservation.

After a stop at the Mummy Cave Ruin, where Indian jewellery could be purchased, we arrived at the farm of Haral's grandmother where he was brought up; it contained a playground with a difference as it included a slide halfway up the canyon wall. The farms are kept in the family and are handed down to the daughters.

On return to Canyon de Chelly, we had a close-up look at the White House Ruin, so called as it is the only ruin with a building having white plaster on the outside. This was once a multi-storied village and the bottom half has been reconstructed in places; even as a ruin it is impressive.

Lake Powell and Glen Canyon Dam

We left Chinle shortly after 8am and headed north for our trip to Lake Powell and the Glen Canyon Dam. As the journey progressed we passed rock formations with the now familiar names of the Glen Canyon Group and the Navajo Sandstone to our right and to our left the Black Mesa which we seemed to be driving past for most of the morning.

A left turn and we were driving over the Morrison Formation before a midmorning stop was made at a Burger King where there was a small exhibit recounting some of the exploits of the Navajo Code Talkers. These were Navajo volunteers who were employed by the US Marine Corps in communicative security roles during World War II. The Japanese were never able to break the code when the Navajo spoke in their own language.

We continued on our way passing more Navajo Sandstone and rocks of the San Raphael Group. As lunchtime approached we entered the town of Page which had not existed until the late 1950s when it was set up as a construction camp to house workers building the Glen Canyon Dam. After lunch we left Page for

the short drive to the dam getting our first sighting as we passed the Navajo Generating Station which burns coal from the Black Mesa to produce electricity.

Figure 11. The steel bridge over the Colorado River at Glen Canyon.

The coach stopped on the eastern side of the Glen Canyon steel road bridge over the Colorado River (Figure 11) so that we could walk across to the visitor centre and get a full view of the front of the dam. This was an interesting experience for those of us who are not fond of heights especially when the effects of passing heavy traffic were felt. At 700 feet this is the second highest steel arch bridge in the United States and prior to its construction a journey of 200 miles was required to get from one side of the canyon to the other. The journey is now only 1271 feet.

The canyon where the dam is located was named by Major John Wesley Powell, after whom the lake is named, who twice travelled down the Colorado River, once in 1869 and again in 1871, whilst working for the US Geological Survey.

Once in the visitor centre we gathered around a topographical plan of the dam and Lake Powell where we were given a short talk: we learnt that the lake had taken 17 years to completely fill for the first time, is some 186 miles long and, with its 96 side canyons, has a shoreline of approximately 2000 miles.

A film followed which showed detail of how the dam had been built. Taking 10 years to construct and using some 5,370,000 cubic yards of concrete the dam has a crest length of 1560 feet, stands 710 feet above the bedrock and 587 feet above the Colorado River.

From the visitor centre observation areas we had time to view the dam and the lake and take those all important photographic reminders of a most impressive construction before boarding the coach to continue our journey to Bryce Canyon.

Bryce Canyon

Bryce was our farthest stop to the north. It is situated on the edge of the Paursaugunt Plateau which is part of the larger uplifted Colorado Plateau. Paursaugunt is bounded on the east and west by the Paursaugunt and the Sevier faults respectively.

Bryce "Canyon" is not a true canyon but the eroded eastern edge of the plateau and is made of lake sediments deposited in early Tertiary times to form the Claron Formation which overlie former Cretaceous grey and brown lake sandstones. The pink/white Claron cliffs are limy siltstones (or silty limestones) whose variable colour is due to iron deposits which seem to glow in the changing light from the east.

Figure 12. Hoodoos in Bryce Canyon.

The whole of the edge of the plateau has been eroded into hoodoos: rock stacks that form monstrous or elegant monoliths as the result of differential weathering under a resistant cap rock

Bryce is amazing in that is consists of a myriad of 100ft-plus high hoodoos in various stages of erosion. It displays amphitheatres of "terracotta warrior"-like hoodoos or "Gaudi" facades to vast cathedral fronts (Figure 12). It truly is a wonderful place with grotesque rock formations stretching as far as the eye can see all glowing pink in the morning sunlight. There is so much to see with over 50 miles of under-the-rim trails. Some of us explored the trails from south to north. This meant a drop and rise of 1000ft over a distance of about 10km but it was well worth it. We seemed to get wonderfully different views around every twist and corner of the trail with the desire to take photographs at every turn and continued to be enthralled by the ever-changing views and formations of hoodoos as the eroded cliff face stretched down into the Paria valley. On the way back to the coach in the late afternoon we were reminded of the altitude as it snowed and sprinkled this fairyland with a delicate white frosting. A truly magical place to be explored further. A place not to be missed on any visit to Canyonlands.

Zion National Park

It is Sunday, bright and clear, cold at these altitudes, but no sign of yesterday's snow. We set out from Bryce under the red rock arch retracing our journey on Highways 12 then 89. "On my right is the Cretaceous, brown/buff, juniper and pine covered." We are now used to these altitude indicators.

We need to pass through a mile long tunnel to penetrate the cliffs into Zion Canyon. As we approached the road wound downwards, cream cliffs standing high on either side. We are in the Jurassic Navajo Sandstone, which is cut by erosion to expose the dune structures. We stop for photos.

The tunnel is narrow so we queue to go through. We pass wave after wave of cliffs high above the road, in the valley bottom, cream sided, patterned with dune bedding, erosion channels draw vertical planes down the rock face, their narrow gorges branching, vertical sided away from the road. Plants, cotoneaster, cactus, pines, oaks, small and bushy, stud the lower cliffs, while near the road the Utah penstamon paints the rock with its red flowers.

We proceed sedately through the dark of the tunnel in the line of vehicles past openings that give glimpses of Zion itself: windows into the red canyon. The road zigs-zags down the valley side; another photo stop as we try to capture the blind arch high in the cliff side, then on down the valley to the visitor centre and lunch.

Figure 13. The waterfall above Emerald Pool, Zion Canyon.

There are many trails enough to last a week, but we had time for only one. We chose the Emerald Pool Trail setting out across the bronze footbridge. The river bubbles over the rocks in the riffle under the bridge and flows on smoothly through the pool downstream, cooling the air and filling it with a muted soporific background tune. We chose the tree-sheltered upper path which follows the river upstream, climbing steadily up the cliff edged with wild flowers and shrubs. We passed up through the Kayenta Formation: repeating layers of sand, silt and mud deposited on delta or flood plain. This is easily eroded which undermines the overlying Navajo Sandstone, causing the fall of blocks of Navajo which litter the hillside. We are heading for the junction, picked out by springs and seeps, green against red, and by the vegetation clinging to the vertical rock surface high above us.

Middle Pool is nearly dry, water trickling over the smooth rock lip where a family rests, baby sitting on the smooth surface agonisingly close to the curved edge that masks the drop into the Lower Pool. We hurry on over the water-worn platform and take the steep winding path over boulders heading up the cliff. We are high above the tributary looking down, through trees, to the valley bottom and up at the cliff now towering above us, red stained vertical slices of Navajo Sandstone splashed with the green of pines which exploit any ledge. It is hot and still in the sunshine that beats down on the path but hikers making their way down the trail reassure us that Upper Pool is close and then, as the trees close in and we move into the deep shade of the cliff, we reach the boulder strewn surface where the pool lies, deep emerald green water backed by the cliff where the junction is marked with springs and seeps picked out by colour change pale to deep red and marked green and black by algae and plants (Figure 13). Tree frogs, heard but not seen, bleat among the trees at the edge of the pool.

We take the lower path down under the waterfall from the Middle Pool, where flowering starbursts, clinging to the rock, live in the spray drifting down from the fall. Here, in the shade, mule deer ignore the passers by and eat steadily, reaching up at full stretch for the leaves just within their grasp. The lower path runs above the river under trees of cottonwood and oak down to the bridge.

Back in the coach by six o-clock, the sun is low on the horizon as we drive, climbing, hairpinned to the cliff wall, up to the dark of the tunnel. Out into sunshine and the white petrified dunes that stand on every side some of them are huge, hundred metres long and fifty metres high, some cliffs made up of series upon series of shallower units, the bases of ancient desert dunes eroded and stacked up, overlapping like cards thrown down after a card game. We drive quiet and sated to Kanab and the next Best Western overnight.

How Grand is Grand? The Grand Canyon

"The trouble with the Grand Canyon is that it is too big" said one of our group members, and that just about sums it up. You can walk for several hours along the rim and not get a significant change in view; you can set off down one of the trails into the canyon and after several hours find you have only descended three rock units. There are similar crags, cliffs, buttes and temples for as far as the eye can see. It takes 6-8 hours to reach the river at the bottom and you have to be extremely fit and determined to do the return trip in daylight hours. The canyon at its widest is 18 miles across and it is about one mile deep midway between the two rims; the north is 5400ft above river level and the south is 4500ft. The river-bed itself is about 2400ft above sea level. Six of the seven climatic belts recognised throughout the world can be found in the Grand Canyon region, ranging from the Mexican desert at the Canyon bottom, to Arctic-Alpine in the nearby San Francisco peaks. Walkers (and geologists) therefore have to deal with altitude, heat, cold and dehydration all in a one-day outing.

The Canyon, carved through the Kaibab/Coconino and Kanab Plateau, contains 277 miles of the Colorado river, although only about 30 miles of the south rim is accessible by road. Some visitor information puts forward a time span between 3 and 6Ma as the time taken to cut the Canyon, but this is not echoed in the *Roadside Geology of Arizona* (Chronic 1983), where no figure is given but a more intricate history of erosion is outlined. Certainly, before the Glen Canyon Dam was built upstream of the Grand Canyon, a massive half a million tons of sand and silt scoured out

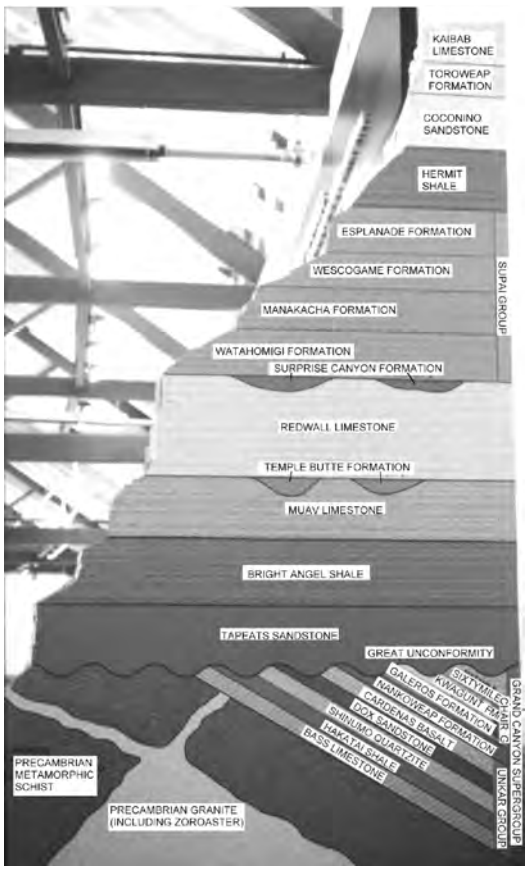

Figure 14. Stratigraphic Column of the Grand Canyon as portrayed in the Visitor Centre.

Figure 15. Looking across the Grand Canyon to the Northern Rim.

the river channel every 24 hours, so erosion was very active until recently. Nowadays the flow is much gentler, but since the dam was built it was noticed that absence of scouring was having a detrimental effect on the ecology of the inner canyon so, periodically, the Glen Canyon Dam side sluices are opened and the Grand Canyon gets a spring clean. The "once upon a time when the river was young" story starts in the mid Tertiary, when the proto Colorado river flowed south from Utah to the east of the uplifted area we now know as the Kaibab Plateau. It took the course of the Little Colorado, now a mainly dry creek, that ran off into eastern Arizona and probably formed a lake. Meanwhile, to the west of this uplifted area (not too surprisingly because it was once very much higher than it is today) another drainage system developed. Eventually, as the head waters of the western drainage system eroded eastwards, the two drainage systems met and, as the route west was the steeper of the two, the Colorado went west and the rest, as they say, is history.

Standing on the Permian Kaibab Limestone that caps the rim - looking deep into the Canyon at the black, heavily folded and metamorphosed Precambrian Vishnu Group schist at the bottom - it is truly awesome to realise that you are looking back through at least 2 billion years of Earth history (Figure 14). It is all there in front of you to be read like a book, every layer, every erosion pattern, every colour, every crinkle in every side canyon just shouts its history at you (Figure 15). Just about every geological process (except glaciation) is represented there. And then, when you have got to grips with all of that, start thinking about all of the upper units of rock now eroded from the top of the anticline that forms the plateau - like the Navajo sandstone whose depth alone reaches 2200ft.

So, where do you start on this truly wonderful illustration of geology? Answer – you can't in 3 days! So my advice would be - just feast your eyes on the sheer magnificence of it - then read the book (Chronic 1983) and then feast some more.

Visit to Asarco Copper Mine – Mission Complex, Green Valley (South of Tucson)

The Asarco Mining Company was formed in 1911 and has grown through the incorporation of other companies over the years. The Mission Mine is but one of their sites. It is leased from the state of Arizona and the Tohono O'odham Indian Nation.

The Asarco Mission Complex Mine is situated about an hour's drive down Highway 19 south from Tucson. This highway is notable in that, for a US route, its distances are quoted in kilometres rather than miles. This is due to the proximity of the Mexican border at Nogales. The mine's presence is noticed for several miles before the access road is reached. The copper ore body was emplaced by hydrothermal action associated with a Cretaceous/Tertiary granite intrusion which was located to the south west of the mine. The ore body is part of a complex fault system and has become detached from its origins and moved as a raft to its present location. The mechanisms of its movement are not clearly understood. The copper mineral being extracted is chalcopyrite, a copper sulphide.

The copper ore is not high grade at only 13lb/ton yielding 28% copper concentrates. At the time of our visit copper prices were depressed and only one of the two concentrating mills on the site was in use. Notwithstanding it being a low-grade ore it is a huge deposit and at full output produces 130,000 tons of copper and $2x10^6$ ounces of silver per year.

The whole mine covers an area of approximately 20,000 acres and was once five individual mines. The mine is a quarter of a mile deep and descends in a series of benches or steps 40 feet deep. These spiral down and provide the working faces and the basis for the track way for the trucks removing the ore (Figure 16).

The ore is released by blasting. At 4.00pm each day a charge is fired to loosen the next twenty-four hours consumption in the mills. The charge is ammonium nitrate/fuel oil explosive placed in boreholes just over 9 inches in diameter and 20 feet deep. It is a complex explosion in that it fires in two stages. The first stage lifts the ore body and the second stage kicks it away from the working face. It is also designed to maximise the shattering of the rock. For safety reasons the charges are pyrotechnically fired - light the blue touch paper and run! Or certainly retire rapidly and leave in the pick-up truck. Electrical firing is not used because of the possibility of a stray signal prematurely setting the charges off. This is clearly a distinct possibility due to the growth in mobile phones and CB type radios in the States, but possibly most likely because of the electrical power used in the mine.

Once the ore has been released large face shovel cranes move in to clear the pile. These are electrically powered operating on 4160 volts connected to an external power supply by a large umbilical

Figure 16. The Asarco Copper Mine; a quarter of a mile deep.

cable. The trucks that are filled by the shovel are diesel electric. A diesel engine drives a generator supplying electricity to a motor in each wheel hub. (You can see from this the potential sources for a spurious electrical firing signal if that system were used.) Each dumper truck has a capacity of 240 tons. It takes three shovelfuls from the crane to fill each truck!

Our visit started with a drive around the periphery of the mine to the viewpoint that overlooks the hole. On our way we passed through the area of bunds that collect the waste material. This arrives as slurry from the processing; 80% of the water is reclaimed for further use. The bund walls are raised progressively until a height of 60 feet is reached. The company is sensitive to the environment. With a simple process of feeding hay to cattle on the spoil the general trampling in of the hay and resulting cattle by-products creates sufficient levels of fertility to host both native and imported plant species. This could have been further improved by a degree of landscaping of the old bunds.

It is difficult to judge the size of the hole from the viewpoint. It is only when you spot one of the trucks or cranes that its impact can be judged. The end of a pen is sufficient to hide them at the bottom. To get the scale of a truck, the viewpoint is home to a second-hand tyre, eleven feet in diameter and three feet thick. The truck then towers a further twenty feet or so above its tyres! One of the features of the viewpoint that found favour with the group was a pile of ore. Apart from the chalcopyrite it was seeded with one of the prettier copper oxide ores showing the characteristic blue/green speckle and stripe. This allowed a general fossick for prizes.

From the viewpoint we moved down to the South Mill which was not in use at the time of our visit. The mill carries out four major processes to concentrate the ore: there are two crushers, a grinder and a flotation process. The first crusher reduces the ore to lumps about the size of a soccer ball and smaller. This is mainly achieved by allowing the ore to fall upon itself in a rotating drum (autogenous process – the rocks work upon themselves). At this stage it may be stockpiled or move directly to the next stage. The second crusher or SAG Mill (semi autogenous) that, in addition to the ore, has 8-inch steel balls which add to the crushing process. The viewpoint ore pile had the remains of some of these balls. They were roughly fist sized and somewhat uneven. These steel-lined mills reduced the ore to roughly $^3/_8$ inch sized particles. To even the wear the mill is rotated in opposite directions for regular periods.

The particles are finally reduced in a ball mill. This mill has thousands of 3-inch diameter steel balls that crush the particles to a talc-like dust. It is only at this size that the copper ore can be released in the flotation process. All these mills are powered by 3000 HP electric motors.

The flotation process requires the ore, the dust comprising copper ore and rock (not to mention ground up steel balls) to be made into a slurry. Water plus a lime product to raise the mix to 8.5 pH, pine oil and specialist other products to make the mix frothy and to get the ore particles to stick to the bubbles are added to the ore dust to make up the slurry.

The tanks of slurry have air blown through them. The resulting bubbles pick up the metallic particles, copper, gold, silver and the remains of the steel balls. The bubbles flow over the edge of the tank break and leave the metallic products. High power magnets remove the steel. The concentrated ore is then further ground and passes through another flotation tank. The ore that sinks is re-circulated to maximise the copper ore capture. The final concentrate is dried and sent off to the smelter.

The concentrate is only 28% rich in copper and represents only 1% of what was removed from the mine! At the time of our visit it cost \$0.98/lb to recover the ore and the market was paying \$0.75/lb! This does seem to be thoroughly uneconomic but the other copper resources the company had were of the copper oxide variety of ores. These cost \$0.55/lb to recover and are reduced in sulphuric acid baths using some of the acid recovered from the smelting of the sulphide ores! It is all swings and roundabouts. It is the massive scale of the 24-hour a day operation that makes it economic. In spite of the depressed price of copper it generates revenues of nearly $\$7.5 \times 10^6$ in Royalties, nearly $\$9.5 \times 10^6$ in State taxes and over $\$1 \times 10^6$ to the Tohono O'odham Indian Nation.

To conclude it would only be correct to take the copper ore story briefly onwards to complete its transformation to pure metal and its place as a product.

The ore concentrates from the Mission Mine are transported to a smelter across the State. They are reduced in a flash furnace which, when heated to a very high temperature with natural gas, effectively uses the ore concentrate as a fuel, mixing it with oxygen and a silica bearing flux. The copper and iron rain out of this combustion, other impurities are bound up with the silica and sulphur dioxide gas is evolved. This is collected and made into sulphuric acid at a rate of 2500 tons/day! It is sold on to other industries as well as being used in the reduction of the oxide ores.

The copper/iron mixture, known as "matte", is tapped from the furnace. It is about 50% pure copper. It is transferred to the Converter furnace where air is blown through the molten metal to remove the iron and any remaining sulphur. The metal this produces is known as "blister copper". Molten copper has a tendency to take on oxygen and form blisters or bubbles within the ingot. The blister copper is 98% pure. It is then moved to the Anode furnace where natural gas is blown across the molten metal burning off the oxygen. It is then cast into copper anodes in a continuous process. These anodes are 2-inches thick by 3-feet wide by 3.5 feet deep. They are then shipped to Texas for the electro-refining process. The anodes are 99% pure copper. In the electro-refining process they form the positive electrode of the process that creates the final product of 99.99% pure copper. The high degree of purity is achieved to best exploit one of the properties of copper. It is a very ductile metal which allows it to be extruded into tubes and drawn into very fine wires. Too many impurities would prevent this.

You only have to take a brief glance around the home to find a copper product; your plumbing, the electrical wiring and all your household appliances use copper. A very versatile metal.

Reference

Chronic H, 1983, *The Roadside Geology of Arizona*, Mountain Press Publishing Company, 321pp.

Vesuvius and Volcanoes in the Naples Area, 21-27 October 2001

Laurie Baker, David Cousins, Brian Harvey, Paul Hetherington, Wilf Walker, Margaret Wenban

An introduction to Vesuvius and the Naples Triangle

Having completed all the necessary car hire documentation, including the extra insurance option, our party of twenty was ready to leave for our first location by mid morning. Our leader Chris Kilburn had arranged a visit to the Osservatorio Vesuviana (Vesuvius Observatory) where we would be given an introduction to the mountain and a guided tour of the observatory by one of his colleagues Dr Mauro Di Vito. Minutes into the journey we realised why Chris had spent so long on giving instructions on which motorway exit to take and where to meet; any thoughts of the three vehicles travelling in convoy were quickly dispelled as we were introduced to the Italian Driving Experience. This was our first experience of the 15km road along the Sorrento Peninsula. I do not think that at any point during the week we were able to negotiate this section of road in less than one hour. Not only did we have to compete with other cars, vans, buses and lorries but also thousands of scooters, double-parked vehicles, oncoming traffic, pedestrians and animals, all with their own individual interpretation of the Italian Highway Code (if such a document exists).

Figure 1. Osservatorio Vesuviana.

We eventually arrived at the observatory to find that our visit coincided with one arranged for some local dignitaries which involved some shuffling of our itinerary and parked cars! Located at a height of 609m (the summit of Vesuvius is 1281m) the Osservatorio Vesuviana is the oldest observatory in the world dedicated to the study of volcanoes (Figure 1). Built as a research centre between 1841-1845 it is still in use today and hosts a major exhibition. From the observation terrace Mauro gave us the history of the volcano (Figure 2).

Vesuvius has evolved in a region forged by volcanism for at least 300,000 years. The present mountain is properly known as Somma-Vesuvius. Somma refers to the bulk of the volcanic edifice while Vesuvius strictly describes the summit cone, constructed during the past 1800 years. Consisting largely of lava flows, growth of the Somma volcano was complete before 25,000 years ago. At about that time Somma's activity changed from modest effusions of lava to catastrophic Plinian eruptions. Five further Plinian events, making six in all, have occurred since then at intervals of about 2000 to 8000 years. Of these, the most famous, and most recent, is the one that destroyed Pompeii and Ercolona (Herculaneum) in AD 79. Since AD 79, volcanic activity has been restricted to sub-Plinian and to the effusions of lava. By 1631, a summit cone (Vesuvius) had been constructed within the Somma caldera. The cone has since continued to grow, reaching its present height during the volcano's last outburst in 1944.

Mauro then guided us around rooms within the observatory, which hosts an exhibition. Here visitors are introduced to the world of modern vulcanology by posters, images, videos and computer simulations. Computer models of previous eruptions have been constructed to define a reliable scenario of the phenomena likely to occur in the case of a new eruption. From such models the risk can be assessed and adequate measures can be adopted to protect or evacuate the exposed population. Another section of the exhibition deals with volcano monitoring. It explains that from the recording and processing of seismic, geodetic and geochemical data precursory signs of an impending eruption can be recognised. A selection of historical instruments, rare scientific books and volcanic products were also on display.

After the observatory visit a quick snack of pizza was suggested for lunch. After some negotiation a room upstairs in a local pizzeria was made available to us and Chris ordered our "quick snack". Ninety minutes later we emerged having consumed a selection of dishes of antipasta, pasta, fish, fried nibbles, breads and 2m of pizza followed by fruit and coffee. All this for £8 a head including drinks and tip!

By now it was late into the afternoon so it was decided that on the way back to Sorrento we would visit the remains of the Roman Villa of Poppaea at Oplontis destroyed by the AD 79 eruption.

Here several sections of deposits from the volcano are in evidence and they generated the first academic discussion of the week.

Figure 2. Party viewing Vesuvius from the Observatory terrace.

Figure 3. Monte Somma from the Vesuvius car park across the Valle del Gigante.

Were the flows pyroclastic or mud? Hot or cold? Etc. etc. Unfortunately, at this stage we began to lose the light but many of the questions were resolved later in the week.

As with the Bermuda Triangle it is very difficult to navigate out of Naples once a vehicle is sucked into its traffic system. What appeared to be, on paper, a relatively straightforward journey back to Sorrento was not to be the case for the occupants of one of the cars. In an experience that was to become quite familiar to us all they extended their knowledge of the geography of Naples through a series of missed turnings, missing or disappearing sign-posts and driving down roads and motorways that took them in the opposite direction to Sorrento.

Vesuvius

Monday started as a glorious clear day with views of Vesuvius across the bay from the hotel. Chris decided that we should seize the opportunity and make the journey to the top of the volcano. We were not disappointed since the fine weather stayed with us all day with only a few clouds passing over.

We drove to the car park which is at about 1,000m above sea level. At this height it was much cooler than lower down. From here it was about a 30-minute walk up to the crater rim. As we climbed the path there were panoramic views across Valle del Gigante (Figure 3), which contains the 1944 lava flow (Figure 4), towards Monte Somma. This forms the outer rim of the caldera within which Vesuvius has grown.

Figure 4. The 1944 lava flow in the Valle del Gigante.

Somma volcano grew to a height of about 2,000m and was complete some 25-30,000 years ago when it changed to catastrophic Plinian eruptions. The collapse of Somma (the rim now reaches a maximum height of 1,130m) means that about 40km^3 has gone in the last 25,000 years. The Somma wall is about 300m of pyroclastic material with sub-vertical lava dykes that jut out from the wall. The dykes are oriented radially around Vesuvius, fed from a central conduit. We also saw evidence of the pyroclastic deposits and lava flows that cover the caldera floor.

The Vesuvius cone is now 1,281m high, reaching that height in the 1944 eruption. Each Plinian event released about 1-3 km^3 of pumice in a few days. The most famous (and most recent) Plinian eruption took place in 79 AD (1,922 years ago), destroying Pompeii and Herculaneum. There had been six Plinian events between 25,000 years and AD 79.

Between AD 79 and 1631 there were about 10 eruptions separated by decades or centuries. Between 1631 and 1944 there have been 18 cycles of eruptions, i.e. virtually continuous. Most of them erupted material of about 10-30 million cubic metres over a few days. During this period there were a few major events of 100 million cubic metres of material.

Figure 5. Crater of Vesuvius.

Just past the ticket office we reached the rim of Vesuvius' cone. The view is dramatic, looking into the crater that is 500m across by between 200-300m deep (Figure 5). The walls are near vertical with scree nearer the base and around the crater walls there are many active fumaroles. The lava layering of eruptions between 1913 and 1944 were clearly observed, as well as the 1944 pyroclastic material that lies on top; at one point a discontinuity that marks the junction between the 1906 and 1944 eruptions could clearly be seen.

We saw examples of leucite and pyroxene phenocrysts which were formed where magma was held in the crust some time before eruption.

The eruption of March 1944 had been bubbling for a few days while the magma entered the crater and pushed out magma that was near the surface. Blocks of magma were seen that were deposited by the lava fountain. The flow was trapped between the base of Somma caldera and cone where it flowed down and then turned north to San Sebastiano.

Vesuvius has been quiet now for almost 60 years and, since development of eruptions during Plinian phases tend towards a more evolved magma, concentrating the volatiles is likely to cause greater explosivity. Therefore, the volcano is monitored continuously and plans have been developed for emergency evacuation that assumes 0.06km^3 of magma will be erupted. Seismic measurements are taken but are of a poor resolution; the style of eruption has oscillated therefore it is not known quite what will happen.

Figure 6. Massa di Somma.

After descending back to the car park it was time to have lunch of rolls, cheese and salami. Driving down the slopes of Vesuvius we made a short stop by the road to look at fine examples of pillow lava and the view back to the peak of the volcano.

Our next stop was in the town of Massa di Somma on the northern flank of Vesuvius (Figure 6). This and the neighbouring town of San Sebastiano were partially destroyed by the 1944 lava. The lava was clearly visible in foundations of buildings (there was even a helpful sign on the flow) that had been erected since. On looking towards Vesuvius the trail of the lava illustrated how it had flowed down towards the towns.

The last stop of the day was at a disused quarry near Pollena which contained deeply eroded pyroclastic material. Here we could also see a very good stratigraphic sequence representing the period from the Sarno Plinian event (17,000 years ago) through to the Pompeii eruption (AD 79). Here we saw evidence of a Strombolian cone with dykes and lava flows while the magma was rising quickly. The eruption probably oscillated between fountaining where fragments come out as a jet and Strombolian, the cone only taking a few days to form.

After leaving the quarry the three cars separated to make their own way back to Sorrento which we all thought would be an easy journey. However, the vagaries of the Italian autostrada and road direction signing caused all three to go the wrong way. One car ended up taking a tour of the autostrada in the suburbs of Naples before getting onto the right road. Another car took the right road south but ended up going towards Salerno before realising they had gone too far and turning round. The third car managed to get all the way to the right turn-off for Sorrento then took a wrong turn to end up in Casellammare di Stabia. Rather than go through the congested town it turned round to find out about limited access to get onto the Sorrento road. In the end, we all arrived back within half-an-hour of each other, just in time to get an evening meal.

Figure 7. Herculaneum.

Herculaneum

On Tuesday we visited the ancient town of Herculaneum, buried nearly 2,000 years ago by the AD 79 eruption of Somma-Vesuvius (Figure 7). Beyond the sound of the ever-noisy traffic, we stood overlooking the uncovered remains of the Roman town before descending to the base of the excavations to examine the details of what had overwhelmed the settlement.

Peppe Rolandi, professor at the University of Naples, explained to us that the town had been built on a much earlier Plinian eruption of Somma, evidence of which was found under the foundations. There are also beach deposits showing that the town was originally on the edge of the sea.

The AD 79 Plinian eruption consisted of a series of surge units followed by massive pyroclastic flows and it was the hot (600°C) surge units that killed the people. The surge units are caused when the column of erupting material from the volcano starts to collapse. The head of the advancing mass becomes dilute and settles as the surge and the main body over-rides it forming the flow. We could identify 6 thin surges separated by 6 flows in the 20m of pyroclastic material. This all happened within a few hours and completely buried the town killing at least 200 people as they tried to escape by sea. They were unable to launch their boats because of the tsunamis.

We spent an hour exploring the remains of the ancient town before eating bread, cheese, salami and fruit "on the hoof," standing outside the entrance.

We then made our way to the Rainieri Quarry which excavates the 1834 lava flow for building stone. Here we saw the remains of a Roman villa and more of the eruptive material of AD 79. We were unable to find the basal pumice but examined horizons of surge and flow deposits. We found a layer of accretionary lapilli, which are pisoliths made by concentric layers of fine ash round a tiny

fragment. These are formed when the eruptive column contains large amounts of moisture. Lack of time terminated the discussion and we eventually found our way back to the hotel.

Campi Flegrei

After once more braving the Neapolitan traffic and the road signs aimed at sending you the wrong way down the autostrada, we arrived at Pozzuoli and our first stop at the Temple of Serapis (Macellum) (Figure 8), the columns of which "are among the most famous symbols in the history of modern geology" (Kilburn & McGuire 2001) having formed the frontispiece in Charles Lyell's *Principles of Geology*.

Figure 8. Temple of Serapis (Macellum) at Pozzuoli.

The marble columns are marked from a height of 3.6m above ground for a further 2.7m with a darkened area caused by the attack of the marine bivalve (*Lithodomus lithophagus*), showing that the columns have been below sea level and have emerged from the sea at least once since they were erected 2,000 years ago.

35,000 years ago, to the terror of the Paleolithic settlers in the area, the whole 50km^2 of the Campi Flegrei erupted throwing 100km^3 of lava and ash into the sky (about 300 times as much as Mount St. Helens in 1980). This ash, or Campagnian ignimbrite, can be found over an area of 30,000km^2.

12,000 years ago an inner caldera covering about 30km^2 erupted forming the Neapolitan Yellow Tuff which has been used as the main building material around Naples for at least 3,000 years.

What is so astounding about the whole area of the Campi Flegrei is its sheer size. Before visiting the area the writer had imagined an Icelandic type of deserted landscape of fumaroles and cones. The actuality is two ring structures, the outer one with a diameter of approximately 15km through which the 'route tangentiale' of Naples tunnels and an inner caldera of approximately 7km diameter. Around this inner caldera there are a number of pyroclastic cones about 300m in diameter and about 80m high. Within the 100 km^2 of the Campi Flegrei crater and caldera, which are still active, live two million people.

From the Temple of Serapis we walked to the ferry port and noted the line of mooring bollards stranded when the land uplifted 1.8m from 1982-4. Further round the bay you reach the old fishing port and Rione Terra, the old centre of Pozzuoli, which was evacuated during the first of the present earth movements between 1969-72. For someone brought up near the tides of the North Sea it is easy to miss the new lower line of mooring bollards and the steps to the water stranded in mid-air. There are of course no tides in the Mediterranean and the land in Pozzuoli has now risen 2.3m in the last 32 years.

Across the bay we could see Monte Nuovo about 3km distant and the Starza marine terrace which has risen 40m in the last 4,500 years. Monte Nuovo is 133m high and 700m across. This hill formed in the two days leading up to 27 September 1538. The ground shook, the sea receded and cold water poured from cracks in the ground. The cold water was followed by steam and mud then a violent hydromagmatic eruption sending wet surges which flattened buildings within 5km. Within 48 hours the town of Tripergole was buried by Monte Nuovo.

From 1501-1538 the ground rose 12m. Today so far the ground has only risen 2.3m in the last 30 years. Undoubtedly magma has again been moving at a depth of 9km and the possibility of a new eruption, perhaps within the decade, cannot be entirely discounted.

From the old port we again braved the traffic of Pozzuoli, this time on foot, to climb past the very impressive Roman amphitheatre, the third largest in Italy. We were aiming for the cone of Solfatara which features in all the tourist guide books of the area. The cone is 300m across and 80m high and inside gives the illusion of space and lack of population. There are fumaroles, boiling mud pools (Figure 9) and even a campsite surrounded by Tamarisk trees. Solfatara is about 4,000 years old and is of a shape typical of hydromagmatic eruptions.

Figure 9. Fumaroles in Solfatara crater.

We had a fascinating day of "hands-on" geology in this small section of the Campi Flegrei but it is still difficult to imagine why so many people choose to live in so dangerous a place.

Pompeii

Thursday was declared a free day, but most of us decided to visit Pompeii. Wilf, Ina and Bill had all been to Pompeii before and so opted for a drive around the Amalfi Coast; they had a wonderful time.

Just for the fun of it the rest of us went by the Circumvesuviana train from Sorrento to Pompeii Scavi. This is the best method of travel - completely hassle free, especially for the drivers.

What can be said about Pompeii that has not been said before? I found the whole experience uplifting and saddening. Only one word can describe the atmosphere of the place - civilized. This was despite the presence of the other tourists.

Figure 10. Pompeii.

Although this was mainly a cultural day, you cannot keep a good geologist down, particularly if that person is Diana Smith. Consequently some of us were treated to a highly interesting building stones walk around the ruins. We even found Rudists in the limestone base of an edifice in the Necropolis.

Over everything loomed the bulk of Vesuvius (Figure 10) as a constant reminder of that dreadful day in AD79 when the whole city became a necropolis and was forgotten for nearly two thousand years. On that sombre note, we left Pompeii after well deserved beer, and took the train back to Sorrento.

Monte Nouvo

Plan A for the day was to drive to Pozzuoli and take the ferry to the island of Procida for a day of geology and swimming. We started well and all three vans arrived in Pozzuoli without getting lost. Unfortunately, the ferry had broken down! Chris quickly drew up plan B: we would take the train to Arco Felice and spend the day on Monte Nuovo, the youngest volcano in the Phlegraean Fields (Campi Flegrei). Unfortunately, the train was not running due to track repairs! With great presence of mind Chris produced plan C: take the bus to the next station and take the train from there. This one worked and after a short walk from Arco Felice we arrived at the Monte Nuovo nature park.

Monte Nouvo consists of a cinder cone produced during a series of explosive events in 1538, destroying the village of Tripergole and much of the port Agrippa. The park, which combines geological and ecological conservation, was established in 1996 by the combined efforts of the Municipal Corporation, the Liceo Scientifico E. Majorana, Pozzuoli (NA) and various local organisations.

Our first stop was an extensive outcrop close to the entrance of the park. A low, pale-yellowish-grey unit was seen tapering out to the right and overlain by a dark grey unit. The pale unit consisted mainly of poorly-sorted angular pumice fragments centimetres or smaller in size with some dense glassy fragments. A crude bedding was apparent in places and a few large clasts were seen to have impact sags. The overlying dark-grey unit was similar in composition but contained a greater number of larger clasts. Closer inspection revealed that some of the pale fragments had dark grey interiors and some of the dark fragments had pale exteriors, suggesting that the colour difference was due to alteration. It is known that the overlying unit is a scoria flow which occurred on the 5th day of the eruption killing 24 people who had walked into the valley. Analyses of the two units have shown that they are chemically indistinguishable, both consisting of K-phonolite. The colour difference is thought to be due to the earlier magma being more vesicular and therefore more interactive with groundwater.

After a picnic lunch we walked up to the crater rim with magnificent views over the Gulf of Pozzuoli and Lake Averno (Figure 11).

Figure 11. View over Lake Averno.

The crater walls drop steeply to the floor some 120m below (Figure 12). An exploratory geothermal borehole in the floor of the crater recorded a temperature of 400°C at a depth of 2km. The Monte Nuovo cone has a low width/height ratio typical of eruptions with restricted hydromagmatic activity. This is in contrast to the adjoining craters of the Averno complex which are very wide in respect to their height, a characteristic of strong hydromagmatic activity. The last eruption in the Averno complex took place about 3700 years ago. The name is taken from the Greek for 'without birds' and it is known that the crater was actively degassing about 2100 years ago. In 37 BC a canal was constructed to the Gulf of Pozzuoli so that Lake Averno could be used by the Roman fleet.

Figure 12. Monte Nuovo crater.

Other points of interest seen from the crater rim were Capo Miseno from where Pliny the younger observed the eruption of Vesuvius, the ruins of the Temple of Apollo (Figure 13) and, on the north west rim of Lake Averno, the entrance to the tunnel which forms part of the Roman canal leading to the west coast. The twin peaks of Monte Gauro and Monte Covara could be seen to the northeast.

It was now time to return to the vicissitudes of the Italian transport system at the end of another excellent day, thanks to Chris's instant improvisation.

On our final day in Italy, we had a special treat planned for lunch. We caught the local bus outside the hotel. This flew up the winding roads, hurtled around hairpin bends and finally deposited us in the centre of St Agata, a small town in the hills above Sorrento.

Lunch had been arranged for us in the Restaurant Margharita by Professor Antonio Pouzzilli, Chair of Mineralogy at the University of Naples, a friend of Chris Kilburn. The restaurant is family owned and run. Professor Pouzzilli joined us for lunch, despite being caught up in the Neapolitan traffic.

Figure 13. The Temple of Apollo on the shores of Lake Averno, viewed from the summit of Monte Nuovo.

As soon as we had taken our places at the table the food and wine started to arrive and did not stop coming. What a wonderful meal! All too soon we were forced to stagger back to the bus stop and were transported at break-neck speed back to the hotel in time for the coach to take us to the airport.

We arrived back in the UK with many happy memories of a great field trip. A vote of thanks is due to Chris Kilburn for his leadership, to Barbara Cumbers for organising the trip and not the least to the drivers who took their sanity in their hands in the Italian traffic!

Reference

Kilburn C & McGuire W, 2001, *Italian Volcanoes*, Terra Publishing.

Book review

The Cambridge Encyclopedia of Meteorites by O Richard Norton, 2002, Cambridge University Press, 354pp, £35:00 (hardback) ISBN 0521621437.

O. Richard Norton, being a fellow of the Meteoritical Society and having a degree in astronomy from the University of California, is the ideal person to put pen to paper on such a specialist subject.

The coverage is extensive, but rather than being laid out in the conventional A-Z format of an encyclopedia this book is arranged in twelve chapters dealing with specific subjects. The first chapter covers the subject of cosmic dust including not only interplanetary dust and meteors, but also the pre-solar grains found in some meteorites. Meteor showers and their cometary origins are explained in detail, including an explanation of which direction to look and at what time to see bright rather than faint meteors. Chapter two deals with meteorite fall characteristics: trajectories, height and angles of descent, velocities and drag are all described in detail with the aid of a few mathematical formulae. Chapter three explains the external morphology of meteorites: their density, shape, orientation and weathering are covered, aided by some basic chemical formulae.

The next six chapters, comprising almost half the book, are then dedicated to meteorite classification. Detailed descriptions are given of the various types, primitives, both ordinary and carbonaceous chondrite, differentiated meteorites comprising achondrites, stony irons and irons. The odd phase diagram aided by some more chemical formulae eases the passage through this section.

Chapter ten, with the aid of the rubidium - strontium ratio as a method of dating, then goes on to explain the relationship between meteorites and the early solar system, and how the information contained within them has aided our understanding of the formation of the latter from the solar nebula. Chapter eleven covers asteroid parent bodies and the meteorites they have produced, while chapter twelve examines terrestrial impact craters and the information they contain.

Eight appendices, a glossary, 285 illustrations and diagrams plus 25 tables and ten basic chemical and physics formulae will add to your understanding of this broad subject matter to a depth comparable with a second level Earth science course.

If you harbour an interest in astronomy alongside that of geology then you are bound to find this book fascinating. If your interest is solely geology then you should make a point of reading this book, it will broaden your horizons.

Mike Steele. BSc (Open), continuing student.

Etna 19-26 May 2001

Annette Kimmich & Chris Crivelli

Day 1: in the beginning....

A 0500 start and 4°C in Zurich, not exactly inviting for this first big trip. Meeting point was Catania airport around lunchtime for most of the 15 participants. Temperature on arrival was 34°C, no luggage (Swissair just forgot to put it on the plane) and difficulties in finding everyone, but at least the transport was waiting. A couple of hours later part of the group is on its way to base camp at Linguaglossa on the northeastern flank of Etna, where other participants have already arrived. The rest will join us in the evening, after a late afternoon flight from the UK. By supper time the group is complete. Due to the two factors, weather and volcanic activity, the programme is to be planned on a day-to-day basis, and day 2 is to be a short acclimatisation period with an outing to Taormina. Before turning in for the night I went outside for a breath of fresh air. High in the night sky, through the trees, a bright red glow and, as I drew nearer to the fence, Strombolian activity could clearly be seen from the summit of Etna's southeast crater as well as an active lava flow. Soon the whole group was at the fence, binoculars were making the rounds, and the talk had turned to all things igneous. This was a great start to what would prove to be a very exciting and informative week on and around the volcano.

Figure 1. Taormina.

Day 2: Taormina (Figure 1)

The weather was perfect. Late morning we all piled into the minibuses and headed for the coast. For a few the beach and sea beckoned, but a larger group took the cable car up the mountain to the village to visit the Greek amphitheatre. Some time was spent inspecting walls for fossils and a discussion started on whether the ashtrays, which were to be found in every souvenir shop, were really made of lava and finally it was decided that this was not the case. This proved incorrect, as a few days later we found postcards with pictures of locals at active lava flows, with forms to press ashtrays from the still fluid basalt.

After returning to Linguaglossa, our leader Boris arrived. An introductory lecture had been planned for the evening, but Boris ordered us to the buses and we set off in darkness up the mountain towards the Mareneve road and the further we drove, the clearer the active lava flow seen the night before became. We stopped in a wooded area with a good view of the summit crater and watched the Strombolian activity producing explosions every few minutes, resulting in new surges from the vent in the SE crater. From this vantage point the flow, which had seemed very small from base camp on our first evening, was quite extensive, with two separate branches, the ends of which were fanning out. It was estimated to be about 2km long and was flowing into the upper part of Valle del Bove. After an hour or so of observations, we returned to Linguaglossa.

Day 3: the first attempt to reach the summit

The weather forecast had been reasonable and so it was decided to drive to Piano Provenzana on the north side of Etna and book a jeep to the crater area. On arrival the air was full of the smell of sulphur, as the wind was blowing the plume directly towards us. The drive up the mountain road was quite an adventure in itself; the vehicle consisted of half bus and half jeep and was specially constructed for the purpose of bringing tourists as near to the craters as possible. Cinder cones and extinct craters dotted the landscape, which was practically void of any vegetation. The road ended at around 2900m, although Mike and Bill could not agree on this, having different altitude readings on their GPS, which resulted in some light-hearted banter on who had bought the better one, and which one, if either, was giving the correct data. By the time we arrived the Scirocco, blowing over from N. Africa, was whipping up a storm and the air was full of dust, but it was decided to at least try to hike up further. However, the mountain guide we met, who had been at the crater area earlier, told us that conditions further up were even worse and an attempt to reach the craters would be very dangerous. By this time the whole group was black from the flying dust, not just faces, teeth too. Disappointed, we turned back and took the jeep down again to Piano Provenzana with short stops on the way on the plateau below the observatory (from which the lava flow was again visible) and at a very impressive crater from which one of the many flank eruptions had been generated. The afternoon was spent on a hike through the forest to a row of cinder cones.

Boris provided the evening's entertainment with a video of recent paroxysms at the SE crater.

Figure 2. Farmhouse engulfed by lava.

Day 4: Etna and man

The day was to be spent exploring the area and the evidence of the influence the volcano has on the lives of the people who live in its shadow. Lava flows from flank eruptions are the events that are feared most by the inhabitants. Activity at the summit craters, although not predictable, does not have the devastating effect of the flank eruptions, which can happen anywhere and without warning and are usually the culminating phase of long active periods. Farms, roads and even complete villages have been victims of these events (Figure 2). The many partially destroyed buildings bear witness to the destructive power. After losing homes, farmers leave fields unattended, sometimes with a chain across the entrance to denote ownership. The people become depressed and move on. Old lava flows, relatively young lava flows, islands of greenery amidst black rubbly hills, trees full of oranges and lemons, but nobody around to harvest.

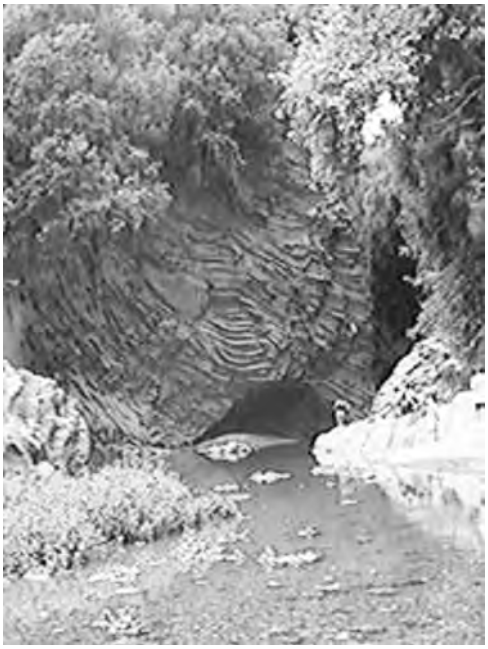

Figure 3. Columnar basalts at Alcantara Gorge.

We drove on to the Alcantara Gorge to the northeast (Figure 3). Here, the geological highlight was the columnar basalts. It used to be possible to wade through the ice-cold water along the gorge, but the water level has been raised, making an extended tour impossible. Before returning to Linguaglossa it was decided to drive to Aci Castello to see the pillow lavas on which the old castle stands (Figure 4). On the way we drove through a thunderstorm and the roads were awash, but we finally reached the coast. The pillow lavas have been uplifted and are interspersed with columnar basalt.

To end a very interesting day, Boris gave a lecture on the tectonic setting and eruptive history of Etna.

Figure 4. Pillow lavas at Aci Castello.

Day 5: The second (successful) attempt

We woke to perfect weather and were soon on the road towards Piano Provenzana. Again we climbed the volcano in the jeep and disembarked at the end of the road to start the climb to the crater area and this time with no wind. The hike took us over old lava flows and snow fields. After a good hour's hike, the crater area was reached, with a first view of the very deep Voragine vent. A small group returned after a brief visit to the craters and the main group made itself comfortable for a long wait until nightfall to get a closer look at the active lava flow. This meant staying until *ca.* 2100 and then hiking 8km back to the minibus. However, the spectacular views of the active SE crater certainly made up for this. The group finally arrived back at base camp around 0200, eagerly awaited by the others, and requested that the bar be opened!! Here's how Chris Crivelli remembers the day.

Wed. 23rd May 2001, Etna, Sicily

"I'll never forget that day. We'd been in Sicily for a few days and explored the lower reaches of Etna - lava flows between ten and several hundred years old - and seen a little of the ancient Greco-Roman ruins which are so well preserved on the island. We had also taken a bus to within a couple of hundred metres of the summit area but had been unable to make much progress on foot towards the craters as there was a driving southerly wind throwing fine tuff into our eyes. We had also observed, every night after dark, the glow of a lava flow effusing from the side of SE crater, the peaceful incandescence punctuated every few seconds by strombolian outbursts from the central SE crater which could be seen, even from our hotel in Linguaglossa 15km distant, and reaching hundreds of metres into the night sky. Two days earlier we had driven round to the south of the volcano to observe the flow of lava by night. The lava flowed south east down the mountain for a few hundred metres before turning through 90° to flow west for a similar distance and then turning back 90° to resume its south-easterly path, the tongue finally fanning out and stopping some 2km from its source (Figure 5).

"On 23rd May I turned my ankle and as I write, over five weeks later, the swelling persists; I broke the zoom servo on my digital

Figure 5. Lava flow by night.

camera and damaged the lens barrel on a borrowed Pentax 35mm camera; I bent and severely scratched walking poles (again borrowed) and I lost a fleece jacket (which my wife never liked), a woolly hat (which I did like), a pair of gloves and half a sandwich (which I could have done with at one o'clock in the morning). These had all been improperly fastened to my backpack. Oh yes, and I ripped an old pair of field trousers. But that is not why I'll remember 23rd May but because that is the day we went to the source of the active lava flow on Etna.

"The area on the east side of the mountain where tourists leave their cars before walking or taking the 4WD bus to the summit area was busier than it had been two days earlier and this time Etna's peak was visible in the sunshine. As we waited for our bus we were hopeful that we could spend more time at the crater areas than on our last try. Our guide for the week was Boris Behncke, a chain smoking, multi-lingual German volcanologist (with a quiff of blond hair that seemed to defy gravity) and self confessed Etnaphile who had studied Etna for twelve years. He claims that Etna is his mistress, that he has had an affair with her for all that time, but apparently his wife doesn't mind because it's only plutonic (he-he, geology joke). Boris's passion for his volcano is reflected in his knowledge of the flows, all of which are known by the year they erupted. Standing on flows listening to the story of their effect on the local people and looking at the remains of homes that had been engulfed I was able to feel maybe just a little of what it must be like to live in the shadow of Etna which towers over the whole north east of Sicily.

"As we went toward the summit area in the bus we passed, for the second time in as many days, the head of the ski lift and the snow was noticeable by its absence. There are, in May, pockets of ice near the summit which are layered with tuff but the ski slopes are lower down the mountain (Figure 6). As we travelled up, the graded track cut through ice several metres thick in places. The vehicle dropped us at about 2900m and here it was noticeably cooler than the tourist area in the foothills and we reached for more layers as we disembarked. Once all off, Boris gave us a pep talk to remind us of the nature of the volcano, unfamiliar to most of us, and pointed to a large rock about 200m away, which was to be our next mustering point. There was the semblance of a worn path but it was not the direct route to our next stop and was covered in pyroclastic debris reminding us of the ephemeral nature of our environment. As we set off using varying routes, some over lava, some through ice, we were, after only a few paces up an incline of 15° or so, soon reminded of the altitude as we stopped to catch our breath. We took this opportunity to turn around and admire the view looking northward over the plains of northern Sicily and out into the Mediterranean. It was misty but we were just able to see how wonderful it would have been on a clear day. As we continued slowly towards the summit area we could clearly see the rim of the Northeast Crater to our left and ahead and, to our right, fumes were drifting into the sky. We carried on up. It was slow work and we stopped frequently as the air, thinner than we were used to, took its toll. Walking over snow, sometimes we sank other times we were held up by layers of tuff, while on the rocks we changed frequently between dark sandy dust and more consolidated debris or lava.

Figure 7. At Bocca Nuova.

"We eventually got to our first destination, the ridge between the NE Crater and the Central Crater, which comprises the 20th century vents Bocca Nuova and Voragine, from where dense white sulphurous fumes came and overwhelmed us and bit into the back of our throats (Figure 7).

" After we had had a chance to take in the barren, unfamiliar, even mystical landscape (and photograph it) Boris pointed out a narrow path round the rim of Bocca Nuova and, urging care, agreed to meet us on the other side of the crater. This was the point of no return as each of us had to decide whether to go on for a further twelve hours to include a 10km night walk down to our cars or return to the drop off point to get the last bus down."

Figure 6. Approaching the summit

Figure 8. Descent into Valle del Leone.

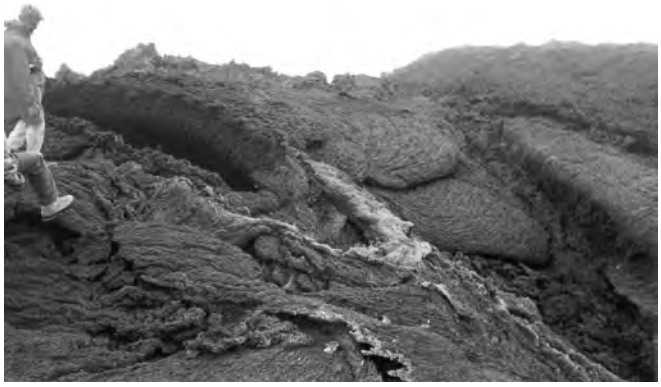

Figure 9. Boris on ropey pahoehoe.

"Sad goodbyes… and we went our two separate ways. We walked round the rim with a gentle breeze wafting fumes around us, now less dense than before. We regrouped at the top of the Valle del Leone from where we could see the cone around the active effusive vent and the strombolian activity from the main vent 100m above it. The valley sides were over 150m deep declining at over 35°. After pointing out the landmarks so clear from our vantage point and again reminding us of the dangers Boris invited us to descend into the valley. Some of the group took the quick way down, galloping over the loose tuff several centimetres deep and slipping around under our boots, the rest of us going more sedately traversing the slope and grateful for the support of our Leki poles.

"We met up about 20 minutes later and sat against a bomb many metres across and ate lunch. This was in the Valle del Leone which was to be our base for the rest of the afternoon while we explored the area waiting for dark to reveal the glow of the active vent (Figure 8). The effect of the fumes receded to be replaced by fine volcanic dust blown up from beneath our feet and sucked into our mouths.

"A few metres away there was the flow of February 2001, predominantly aa formation but in places ropey pahoehoe had formed and as we carefully walked over it we found it to have a hollow feel (Figure 9). It was the roof of a lava tunnel with lava still flowing gently through it and in places still hot with white ash

Figure 10. Inspecting a fumarole.

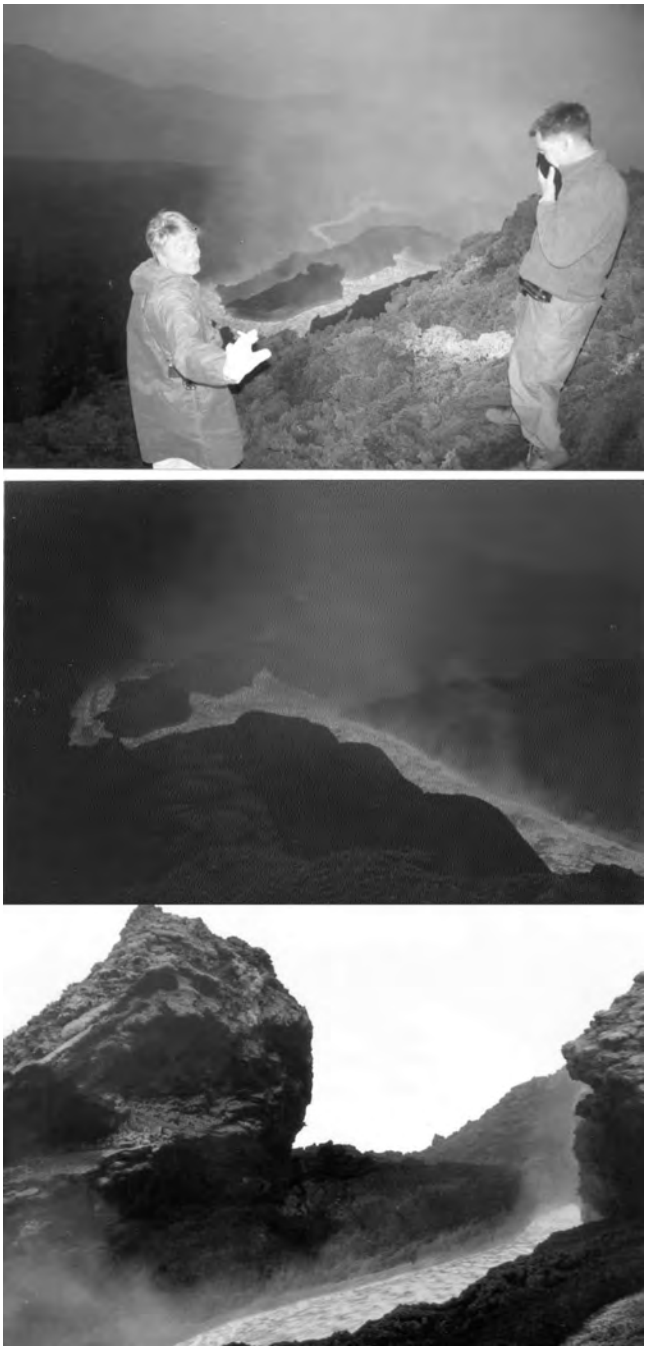

Figure 11. At the vent.

deposits. The flow stemmed from some 150m above us, near the active vent but after reconnoitring further up Boris felt it was too difficult to attempt as a group.

"We settled down and explored the lower reaches of the flow. A gentle wind was swirling around and occasionally bringing acidic fumes from the Bocca Nuova towering above us. From time to time the direction changed and the wind blew over a fumarole which brought its warmth (Figure 10), a welcome change to the falling temperature as the sun set behind the top of the valley. It is a magical place, rugged, primordial, dark rock everywhere and devoid of all life.

"Some time later three figures appeared at the top of the slope. They scaled down the slope and introduced themselves as journalists come to photograph the active vent. We watched them

scrabble up the active flow and as we watched we discussed how we felt about getting up there. Not all of us agreed we would go. We asked Boris when he thought we would next get to the vent and after a second or two replied 'now, if you like'. Well, we did not need to be asked twice and having reviewed the scene Boris led a small group of us along the base of an old flow (rather than up the levee of the live flow itself) and up to the now glowing vent (Figure 11). After about 20 minutes we approached the vent area. There was a noticeable hiss of degassing at the vent and cracking noise as the surface of the flow cooled and solidified on exposure to the air as it rode along on the molten lava underneath. We stood and watched the flow of about $5ms^{-1}$ and at a temperature of over 1000°C dogleg down the mountainside as we had seen it from below days before (Figure 11). When we rejoined the group it was completely dark and the mountainside glowed bright red from the main flow and random fumaroles We had a four-hour walk ahead of us. The torches were indispensable as we helped each other over two or three kilometres of rough pyroclastic fallout until we got to the graded track where the walking was easier. Four hours later we arrived back at the vehicles tired but elated and we drove almost in silence back to the hotel. It was nearly 0200, later than expected, when we arrived and the early returners had kept the staff up to allow us access through the security gates and to keep the bar open. No - I'll never forget that day."

Day 6: Etna and man (continued)

Another day around the volcano, inspecting lava tubes, derelict buildings and ancient cones, this time on the south side. At one point on the newly-built road, a halt was made to see the damage caused by newly-opened fissures, which had caused a wall to crack in two places, forming a picture-book graben. The fissures have their origin at the SE crater, and have propagated downhill at a speed of 1km per day. The new road had been cut through a lava flow, which could thus be seen in cross-section, with the red baked earth below. Boris had to leave later in the afternoon, but we would be seeing him at our farewell dinner next day.

Day 7: Siracusa

Our last full day had been planned as a day of relaxation after all the hard but enjoyable work. Our destination was Siracusa, around 60km south of Catania, to visit the archaeological park and, for a change, we were soon driving past limestone scarps instead of lava, and the incredible colourful flora. A pleasant day at the park with its Greek and Roman amphitheatres carved out of oolitic limestone ensued and towards evening we headed back along the autostrada to celebrate a successful week with food and wine at a restaurant in Acireale, where we would be staying overnight. Boris joined us for this feast, during which we managed to eat our way through practically the whole menu, including an excellent mixed grill of meat and fish, cooked over Etna lava stones, a fitting end to an unforgettable adventure.

At this point I would like to thank those who helped to make this first big trip for OUGSME such a success: all the group participants for their good humour, ideas and constructive criticism, our drivers, who brought us to all venues with no mishaps, despite having to contend with the erratic driving practices of the Sicilians, Mike Molloy for his prudent management of our collected funds and of course Boris Behncke, our Etna expert and, by the end of the week, good friend, who gave us a detailed insight into the workings of this amazing mountain and its impact on the lives of the islanders. I sincerely hope that we will be able to repeat this trip very soon.

Postscriptum

After the group returned, a strange restlessness was felt by most of the participants, difficulties in settling back into normal routine. Mails were exchanged, often voicing the wish to return as soon as possible. The volcano seemed to have a lasting influence and the feelings increased the strong bond already felt by most of the group. The contacts amongst group members continue to this day, with visits and regular mails. The July 2001 eruption gave rise to many a discussion, and despite the short duration of our visit, it was apparent how much we learnt and how great the wish was to learn more ...

Post-postscriptum

Piano Provenzana was the starting point for our two attempts to explore the crater area. It was, in May 2001, a verdant plain with shops, restaurants, souvenir shops, ski school and the ticket office for the four-wheel drive bus trips to within 200m altitude of the craters. It is used more by locals than the masses of foreign visitors who tend to use the tourist complex on Etna's southern flank. Provenzana and the adjacent Ragabo forest have a rugged beauty that belies its dramatic beginning as part of the ancient Mongibello formation. However on 27th October 2002 the area was devastated by lava flows and earthquakes and finally the tourist buildings that remained standing were peppered with bombs as Etna reclaimed what she had created over 8,000 years ago. For more information see Boris Behncke's excellent website http://boris.volcanoetna.com/ Pianoprovenzana.html

Book review

Teach Yourself Volcanoes by David A Rothery, 2001, Hodder and Stoughton, 266pp, £8.99 (paperback) ISBN 0340790474.

Another little gem from the pen of Dr Rothery. The book is broken down in 10 easy reading chapters that highlight all aspects of volcanoes. The early chapters describe the types of volcanoes found, the types of eruptions that come from them and the hazards caused by them. Topically Chapter 6 discusses volcanoes and climate and how volcanic eruptions affect our climate. Chapter 7 is informative on modern day techniques in monitoring volcanoes so as to manage the hazards caused by them. Chaptes 8 and 9 discuss the reasons why people live close to volcanoes and "volcano tourism" i.e. which volcanoes can be visited and how to do it safely. Last but not least is Chapter 10, which takes us on a trip into space to visit extraterrestrial volcanoes. Throughout the book there are plentiful black and white photographs and diagrams that are easy to understand. The centre of the book contains some stunning colour photographs of volcanic eruptions and their devastation of the surrounding countryside. A glossary and three appendices found at the back of the book would be of great help to any layman who wishes to understand the phenomenon of volcanoes.

Sue Vernon BSc Hons (Open)

Branch Reports

East Anglia

East Anglia began with the best attended event of the year, the AGM and Day of Talks. Dr Simon Kelley talked about the 'Fore arc basin in the Antarctic Peninsula'; Prof Nigel Harris told us about the 'Tibetan Plateau, when did it go up?' A buffet lunch followed and a chance to see the new venue, Milton Country Park. Then Dr Nigel Woodcock from Cambridge University talked about the 'Early Palaeozoic Geological History'. The AGM followed the talks. The branch had one other talk in September by Chief Inspector Greeney who told us about his experiences of the volcano whilst working on Montserrat as he had access to places most people were unable to visit.

A new member, Elvin Thurston, offered to lead a trip to a sandpit near Norton Subcourse (a village in Norfolk). None of us had heard of the quarry in the Norwich Crag but the prospect of fossil finds drew the largest number of people on a field trip this year; it was very gratifying to see so many people turning up in April. The trip to Charnwood in May had to be cancelled for the third time as the leader was unable to attend. Bob Markham, who used to be curator at Ipswich Museum, led an evening walk to look at the springs in Christchurch Park. This was not too well attended but there were plenty of springs due to the wet weather. In July with the rain still falling, a barbecue was held in my garden, luckily undercover of a gazebo. We looked at the large 'Icepits' in the nearby wood, which we concluded were probably due to extraction by man a long time ago.

We will end the year with a repeat trip to Winterton-on-Sea with Richard Newman, another branch member, to look at the seals and the sea defences. The seals have their pups in December and can be seen on the beach, although our trip may have to be cancelled due to the seal virus. Rocks used for the sea defences provide us with some exotic rocks, such as some wonderful Norwegian Larvikite.

The end of May weekend trip to Derbyshire had to be cancelled due to the Government changing the date of the Bank Holiday. Dr Gareth George led the Winter weekend to the Gower, where we visited Caswell Bay, Three Cliffs. Overnight the gales came and Sunday at Ogmore was extremely windy but the geology was excellent.

March saw the first East Anglian foreign field trip to Almeria. Dr Jason Wood, who had just joined the department at the OU, took twelve of us around the region where he had been working. Driving was entertaining and fast but the geology was interesting and varied, including limestone reefs, canyons, badlands, dacite, volcanics and phyllites. The week ended with a visit to the Alhambra which will be reported in the next Branch Newsletter.

Symposium this year was at UEA in Norwich, many branch members were involved and we recorded the greatest number of East Anglians ever to attend a symposium. For the first time East Anglia produced two displays, one on Almeria and a past visit to Sutton Pit in Cambridgeshire.

The branch has had a full year apart from the events cancelled in May. We have had some very active new members this year but it is mostly the same people who attend events and who represent a very small percentage of the total branch membership.

Wendy Hamilton

East Midlands

The year started with our AGM at Wollaton Hall in Nottingham, followed by Colin Small giving us the new version of his 'Fly 'em, or fry 'em' talk. With volcanic dust, sand and birds flying into aircraft engines Colin did a wonderful job convincing us that flying is still a very safe way to travel.

In February we held the Branch Dinner at the Otter, Kegworth, and in March there was a joint trip to the Natural History Museum in London. Sadly our members showed very little interest in either event.

For Easter 2002 Dr Graham Smith led a very enjoyable trip in East Lothian region. We visited Oxwellmains Quarry and Cement Works, Catcraig Beach, Dunbar Harbour, Grantshouse Quarry, Hoardwell Coppermine, Edinshall Broch, Gosford Bay, Bangley Quarry, Arthur's Seat and Salisbury Crags, the Royal Museum of Scotland to see the Hugh Miller exhibition, and Glenkinchie Distillery. By popular request Traprain Law was visited twice. But the high spot of the week was Siccar Point. This proved a vertical challenge to several members but all were agreed it was worth the struggle. At the site James Hutton and Dr Playfair's report was read aloud to all. In keeping with East Midland residential trips we had several mishaps: one stolen car, three breakdowns, one set of keys locked inside and two cars hit by moving objects as well as a dislocated shoulder that required a very late night trip to find a hospital in Edinburgh.

Our Basic Geology Day at the National Stone Centre had a disappointingly low attendance: eleven people turned up of which only four were S260 students, but the latter benefited from plenty of help in understanding dip and strike.

In May we visited South Ferriby Quarry with Les Richmond. The morning was spent in the quarry looking at how it operated and examining an Upper Jurassic/Cretaceous unconformity. After viewing the Humber Estuary we visited Mssrs Wm Blyth's Tileworks at Barton-on-Humber. Local clay from the river's edge is used to hand-make tiles as they were made in the 19th century. Dr Albert Horton lead an exceptional trip in June to look at the geology of the Nottingham area. Outcrops at various locations around Nottingham University were studied. This was followed by a visit to tunnels under Nottingham Castle. The afternoon was spent at Gunthorpe looking at the Mercia Mudstones.

July saw us taking a walk around Raunds town centre to look at the local geology. At first glance there appeared to be very little to see, but Carol Warcup soon proved to us that was not the case as we moved ivy and weeds to peer at rocks behind. We had permission to look at the rocks behind a local factory and this proved so interesting that no one wanted to leave.

Griff Quarry, near Nuneaton, was visited in September. An interesting morning was spent looking at the diorite, granite and shales and discussing the environmental management that is necessary today. Our September Newsletter contained an article by Dr Sid Burdon, one of our branch members, on the Geology of New Zealand. To continue the theme Sid also gave an illustrated lecture on the country. One hundred slides on each of the islands left us all wanting to visit the country.

The weather forecast for Sunday 20th October 2002 was for rain and gales but this did not deter sixteen hardy members from attending Harry Briggs' trip to Ashford in the Water and Monsal Head, Derbyshire. We set off up the hill to a superb viewpoint at Monsal Head, pausing *en route* to view the surrounding countryside, noting the course of the River Derwent and prominent land forms such as Longstone Edge. We made our way down into the Wye valley to Hobs House Quarry; the coral band is about a metre thick and made up of colonies of *Lithostrotian* and *Syringopora*. After walking through Great Shaklow Wood we passed the closed tunnels of the Ashford Black Marble mines. Yet another excellent trip from Harry, his local knowledge smattered with history and (of course) geology all contributed to our greater understanding of the geology and geomorphology of this area. And the rain held off until almost the end!

The following Sunday saw us undertake a new venture, a Sunday morning lecture; this was in response to our members saying they did not like to drive on dark winter nights. Dave Rothery gave an excellent talk on The Geology of Jupiter's moons and satellites and afterward many members stopped for lunch and the chance to discuss the talk.

Snowflake visited Hunstanton this year. Saturday was spent on Hunstanton Beach looking at the Carstone red and white chalk. There was then a beach traverse looking at modern shell (mussel) communities and digging holes in the sand to look for the black anaerobic layer. On Sunday the Cromer-Holt Ridge was visited to see if it was an end moraine, before descending to Cromer Beach to look at glacial deposits and the underlying chalk. Dr Roy Clements of Leicester University proved an excellent leader.

Glynis Sanderson

East of Scotland

After the disruption of the previous year, 2002 has been almost predictably straightforward with all our arrangements going to plan - well, almost!

Our AGM in January was reasonably well attended and our guest speaker, David McAdam, brought us up to date with developments in the field of RIGS. Only parts of our area are covered by RIGS groups, but those which are operating are making a useful contribution and it is good to see some of our Branch members participating in this activity.

Our first field trip was to South Queensferry on a misty day in April. Andrew McLeish introduced us to the remarkably varied rocks along the short stretch of shore from just under the Forth Bridge eastwards towards Cramond, and enlivened the trip with many an anecdote about the history of the area as well as the geology.

In June we visited the Comrie igneous complex, under the expert leadership of Ed Stephens, and examined the intricacies of its metamorphic aureole, slithering precariously up and down steep slopes made even more treacherous by several previous days of rain.

A quick change of plan saw us at Collieston in August. Led by our own Branch member, George Downie, we examined the splendidly convoluted folds and metamorphic rocks on the cliffs north of the village and the shore to the south.

The final trip of the season was to Carmyllie just after the end of the OU exams. Lyall Anderson had promised us fossils and thus attracted a record turn-out for a day trip in this area. The quarry was alive with the sound of three dozen hammers and everyone went home with at least one fossil, though nothing spectacular was found.

We were happy to welcome several members from other Branches, notably the West of Scotland, and we also hear that some of our members have enjoyed trips organised by the West of Scotland Branch and other Branches.

Although it was not an OUGS trip, the Branch was well represented on the Glasgow-originating 'geological tour' to the Colorado Plateau and Yellowstone in September.

In conclusion, I would like to thank my small committee for all their help and support: in no particular order, Angus Macpherson for looking after the funds, Paul Speak for producing an excellent set of newsletters and Doug Palmer for his part in organising events. We are also most grateful to our leaders Andrew McLeish, Ed Stephens, George Downie and Lyall Anderson and to our guest speaker, David McAdam and, last but not least, to the members for supporting the Branch throughout the year.

Anne Burgess

Gogledd Cymru

We started the year in January with our AGM at Wrexham, which was followed by a very entertaining and informative talk and slide show given by Fred Owen about his trip to Patagonia.

March saw our first trip of the year with two very knowledgeable leaders, Dr Rob Crossley and Brian Waugh, to Thurstaton looking at the sandstones and was thoroughly enjoyed by the few who attended. April saw a hardy group of us tackle the worst weather of the year so far and make the trip to Porth Neigwl (Hell's Mouth) at the far end of the Lleyn Peninsula with Norman Harrison. A few drenched and windswept souls bravely carried on to be rewarded with a detailed guide to the geology of the area.

By May the weather had picked up. Dr Will Jones was to lead us on our trip to Nant Ffrancon but, due to work commitments, was replaced at the last minute by Jonathan Wilkins who not only was a knowledgeable leader but also displayed some remarkable hill climbing abilities akin to that of a mountain goat!

Sadly, our June trip to Holt to look at geo-conservation had to be postponed until a later date as our leader, Dr Cynthia Burek, was poorly. We look forward to this trip next year, as we do our trip to the lead-mining area of Minera which, unfortunately, also had to be postponed.

In September, a large group, with numbers swelled by members from South Wales GA, tackled Moel Siabod. Hadyn Roberts successfully led a group to the top for an amazing view while some of us explored the geology of the lower quarries and that of Capel Curig. In November Sue Hughes led a very interesting trip to Criggion Quarry and Nesscliffe where we saw spectacular views over the wonderful mid-Wales landscape. We also learnt that this quarry has an interesting way of moving blasted material from the top of the quarry to the more finer processing units via a 250m chute!

Our members and committee have again been extremely busy on all fronts geological. Fred Owen has worked brilliantly and tirelessly to increase links with other geological groups in Wales and the North West. Ann Sunning has worked hard to produce our newsletter (not an easy task), Sue Hughes has kept our finances in order, Tony James and Rachel Atherton have been extremely supportive and continually beaver away in the background. I was involved in the UKRIGS Conference in Llandudno in October and, in April Fred, Tony and myself attended the expanding Wrexham Science Festival.

This is my last year as Branch Organiser as I shall be standing down at our AGM. During the last four years I have seen the branch start to expand not only in numbers but also with links to other organisations. I have had the opportunity of seeing some truly wonderful geology under the guidance of superb leaders for which I and anyone who has ever been on a trip thank them. My thanks also to the excellent committee members that I have had the pleasure of getting to know and working with. Without them, their efforts, support and guidance, I would not have learnt half as much - and half as much would not have been done! Thank you. I wish the branch and everyone in it well. Most of all, I look forward to next year and getting back out in the field!

Wendy Owens

Ireland

This has been a quiet year for the branch; branch membership now stands at 42. The AGM was held in Trinity College Dublin in January and was well attended; the building stones walk which was to follow the meeting had to be cancelled due to the meeting overrunning, but Patrick Wise-Jackson was good enough to provide all the members present with a complimentary copy of his book "The Building Stones of Dublin". Hopefully we will all put it to good use.

In April Tony Lee took a small group to Bellshaws Quarry for a mapping exercise. Bellshaws Quarry must be one of the best geological sites of all time for newcomers to geology with text book examples of stratigraphy, several small faults clearly showing displacement and dykes cutting through the quarry.

May arrived and Alan Bell led another trip for us to the Mournes to look at the Mourne Granites. This was a great day with the morning spent on the beach looking at the Silurian turbidites, deep water sandstones and shales which formed as the Iapetus Ocean was closing. We took lunch sitting on granitic boulders at the side of Bloody Bridge river, then continued along the river looking at the different granites on the way: the G1 granite being much lighter in colour than the G2. We finished up at the quarry where we examined some large boulders which had been discarded by the quarrymen.

On the June bank holiday weekend Bettie Higgs led a very well attended trip to the Burren. We started on Saturday at Black Head looking at the limestone beds which dip gently to the south. The clints and grykes are typical of the karst scenery of which the Burren is so famous. Above the road there is a horizon which contains distinct *Lithostrotian* hexagonal corallites. At Murragh we took a brief look at a large calcite vein, which contained some very large calcite crystals, before going to Fanore beach to look at the dunes. Travelling south we came to Ailledie North where we examined a clay wayboard; these clay wayboards clearly mark the base of each of the limestone terraces. At Ailledie South we were at the base of the terrace limestones where there is an abundance of fossils: solitary rugose corals, crinoids, colonial corals and bivalves. After lunch we visited Mullagh More (see OUGS 30th Anniversary booklet) which is gently folded, and clearly shows the terrace limestone sequence. On

Sunday we visited Fisherstreet strand to look at the cliff section; this is mainly unfossiliferous shales which contain abundant iron pyrite nodules, although there is one band which contains *Goniatites*. We concluded the trip with a visit to the spectacular Cliffs of Moher

At the beginning of November Susan Pyne took us to Ballyknockan to look at the Quarries where Leinster Granite has been extracted over the years. Many of Dublin's fine churches were constructed from Ballyknockan Granite. Although there is very little granite extracted from the quarries nowadays, evidence of the stonecutters' art abounds in the surrounding walls and buildings.

I would like to thank all our leaders for their time and efforts. I would like to thank all our members who attended the trips and I would like to thank our branch committee for all their efforts and support.

John Leahy

London

Another year of interesting and varied events has passed. The year was brought in with the AGM and a lively talk, "Fly Them or Fry Them" given by Colin Small of Rolls Royce on the problems of jet engines and their interaction with sand. The monthly talks have continued throughout the year and have covered such topics as Flood defences, Building Stones, The Aberdeenshire Gabbros - a Geochemists Tale, Aspects of Fossils, Travels to Brazil, Madagascar, The Aegean and the Grand Staircase Traverse of the USA.

In February, a large party explored London's geology as detected from Hampstead Heath. In March the Branch offered S260 students a Tutor/Committee led field trip to Herne Bay. In April we visited the Hog's Back led by Brian Harvey. This trip had been held over from the previous year due to the Foot and Mouth crisis.

In May a small group of members went underground in Hartham Quarry. This quarry extracts the Inferior Oolite for building stone. A visit to Avebury on the way home from Hartham concluded a very pleasing and interesting event. The Spring bank holiday was spent with Paul Olver on Anglesey. The June field trip was to Munday's Hill Quarry in Leighton Buzzard with Jill Eyers. In July the Branch walked the Albury Geological Trail in the company of Iain Fletcher whose work with Surrey RIGS and other interested parties was instrumental in setting up this trail. Our July talk was replaced by an evening building stones walk with Eric Robinson around the South Bank Complex. The highlight of the evening was a " flight" on the London Eye allowing the group to get a "bird's eye view of London. In August, members of OUGS flew off to the Sunshine Isle of Bornholm in Denmark for a week's superb geology with Richard Bromley and his wife Ulla. Repeat visits to Brookwood Cemetery and Dorset made for a busy September. The October trip had the Branch looking for "Chedworth Buns" (an echinoid) with Neville Hollingworth. Our winter week-end led by Martin Allbutt in Shropshire around Shrewsbury and the Long Mynd was a great success.

Other events included manning a stall in the OU Earth Sciences marquee at the OU Open Day in June, running the annual S260 Revision Day at Royal Holloway in September and in November several members of the Branch manned a stand for the OUGS at the GA Reunion held in University College.

Congratulations go to Sue Hay, a long standing Branch member and Committee Member on gaining her PhD. Sadly for the Branch, Sue has recently relocated to Hereford, so our loss is another Branch's gain. We thank you Sue for all your hard work. Congratulations are also in order for another Committee Member, Dawn and her partner Stewart on their new baby. As Branch Organiser, I would like to thank the rest of the Committee for all their hard work throughout the year. Without their help the Branch would not be able to run so many varied activities for the members.

Sue Vernon

Mainland Europe

Somehow it does not seem like a year since I last wrote my report. So much has been going on and time has passed so quickly. Our OUGSME year started with the AGM in Brussels where we were able to welcome the OUGS chairman for his first visit to the branch. He was pleasantly surprised at the close-knit group that has evolved since our inaugural meeting. Normal proceedings over, we were treated to a lecture on 'Sustainable Development' by Professor Jacques Nihoul from the University of Liège, a subject which generated many questions and was well received. The weekend also included a visit to the dinosaur exhibition at the Natural History Museum and a stroll through the city. A minor difficulty arose when the restaurant booked for the Friday evening get-together was closed by the police under suspicion for gun-running and money laundering, but a substitute venue was soon found. Our thanks to Ole Nielsen for organising such an enjoyable weekend.

Unfortunately, we had to part with our newsletter editor, Ann Cripps, early in the year; however, she remains a member and we hope to see her at a future event. Her place was taken by Kirsty Crocket, who has settled in well and introduced some new ideas. The advertised Whit weekend was cancelled owing to lack of bookings; the reason lying in the spontaneous invitation at short notice and nobody being able to fit it into their own tight schedules. A second try is planned for next year.

In July some thirteen people met in Arbois, French Jura, for a week exploring the region, an event organised by Elisabeth d'Eyrames who put a lot of work into her programme and found a host of experts for various aspects. Professor Chauve took us on a trip along a cross-section of the Jura mountains which was the basis for the following excursions. Professor Davaud from Geneva University, together with some of his students, introduced us to a reef complex with interesting fossils and Professor Mettetal, a hydro-geologist from Besançon, gave us a guided tour of the area for which he is responsible. Various soils producing different wines were part of the varied programme as well as visits to caves and to the salt wells of Salin-les-Bains. So many people contributed to this interesting week, visitors accompanied us and generally a good time was had by all. Thanks to Elisabeth for her hard work and hospitality and to all those who were willing to share their expertise and to give us an insight into this geologically very complex region.

As I write this report, in thought I am still on Santorini, our last port of call for the year, having only just returned. Nine of us met in Athens airport for the short trip to the islands. Thanks to the field notes put together by Marika Vespa, doctoral student in Freiburg in Breisgau, Germany, we were able to undertake the trip without an expert leader. The notes proved invaluable to find the various exposures which often were not mentioned on maps. We spent seven days of perfect weather climbing up and down cliffs, visiting quarries and enjoyed a day in the caldera, sailing from island to island. The friendly islanders were always willing to point us in the right direction and share their information. Not only did we get to see some spectacular geology but also made many new friends who introduced us to the history and culture. The OUGS 'geologos' became a part of their daily lives during this short time and our interest for their island was appreciated greatly.

I am pleased to be able to announce that OUGSME finally has an official bank account. Just as we were beginning to think that there was no solution to this problem, Nora Barrett with the help of husband Frank, finally came up with a result. As soon as possible, the various accounts in different countries will be consolidated into one. Between our trips, studying and exams, plans have been made for next year. The AGM will take place in Luxembourg. Preparations for the Greenland trip are in full swing and another post-exam week is on the drawing board. Several ideas have been submitted for other places of interest and I am sure that the programme for 2003 will be expanded. So many members have contributed to this year's programme in many different ways and I am grateful for the help from each and every one. OUGSME has established itself as a regional branch and goes from strength to strength, thanks to the commitment of its members and the committee, who have supported me and who continually motivate me in the development of our group.

Annette Kimmich

North West

Our January lectures this year were held at Lancaster University, the subjects were, 'A Glimpse of the Canadian Rockies', followed by

'Conservation of Limestone Pavements'. The branch AGM was held on a Saturday evening in February ending with a dinner at the same venue.

March saw the establishment of our branch website which grows from strength to strength. The first outdoor meeting in March was to the Wrexham Delta Terrace, this involved using quarries, landforms and sediments as evidence of its existence and the resulting effects of glaciation.

A 'Beginners Mapping in Chapel-le-Dale' was our event for April. The aim here was to map the basal Carboniferous unconformity with the Ordovician around the valley by visiting easily accessible road-side exposures and small quarries all a short distance from parking areas, ending the day with a visit to White Scar Caves. It was thought that this would also be a good venue for members who may find difficulty in attending field trips over rougher terrain but, unfortunately a very disappointing turnout ensued. Early May found the branch in North West Scotland, based at Ullapool, where we were able to enjoy four days of glorious weather and the scenic delights of Loch Assynt, Enard Bay, Laxford Bay, Scourie Bay and Tarbet; at the latter we came into contact with some of Britain's oldest rocks as we explored the Lewisian and Torridonian formations. Later in the month we accompanied the Manchester Geological Association for a joint trip to Staffordshire to look at the Roaches. After visiting Ramshaw rocks in the morning the afternoon was spent on the elevated heights of the Roaches and Hen Cloud.

Cumbria was the venue for our June event which would take us to areas around Torver to study the turbidites, minor intrusions and landforms of the Windermere Supergroup. We were joined by a number of members from the Cumberland Geological Society on this trip which began in extremely wet conditions, however, the day improved and all felt it was worthwhile when our final location took us to Foxfield to view the massive vertical face containing hundreds of sole structures which must be one of the best examples of this kind in the country.

In July, a further joint trip, this time with the Yorkshire branch, went to Settle and Malham to look at the Silurian/Carboniferous boundary. Disappearing streams (water sinks at Malham Tarn) and re-appearing streams (Malham Cove) were the order of the day. Enhancing this trip was a visit to a partly restored Hoffman limekiln of massive proportions just outside Settle. Limestone pavement features became the object of our attention during August by a visit to Great Asby Scar near Orton, South Cumbria. The GA Earth Alert Weekend was also held in August and was attended by a number of branch committee members who, together with Yorkshire branch colleagues, ensured the representation of our society by providing and manning an OUGS stand at the venue.

At the beginning of September the OUGS S267/268 Revision weekend was held in Penrith; a number of members of the NW branch committee were once again greatly involved with the organisation and support of this event. The second long weekend of the year was held mid September in Pembrokeshire, looking at the effects of the Variscan orogeny on part of the South Wales coastline around St Davids Head. The events in September ended with a Revision Day held in Chester which was a joint venture with the North Wales Branch. Approximately thirty students booked in for the day to brush up on the topics relevant to S260 and S269.

Our October outing was to be a Geowalk around the grounds of Lyme Park in Cheshire but it coincided with one of the worst days of the year for weather. However, twelve people turned up and braved the wind and storm for a couple of hours and enjoyed a somewhat curtailed itinerary. The last outdoor event is to be held in November when we will visit the Carboniferous sandstones around Rivington, Lancashire, looking for evidence of glaciation, coal and lead mining. To round off the programme for 2002, our final winter lectures will be held in December at Middleton when the topics will be, 'Isotopic Analysis of Pyritised Fossils', 'Fossil Cold Seeps' and 'Dinosaur Food' .

The current branch membership stands at 265; with lapsed members being replaced by new members this represents an increase of 6% over last year at this time. Once again we have enjoyed another period of varied, informative and interesting field events. My thanks for another successful year go to the branch committee, leaders, lecturers and all members who have contributed.

Alan Diggles

Northumbria

Following some upheavals in the branch and the unfortunate resignation of Linda Lane Thornton due to pressure of work I have been asked to step in as Branch Organiser until the branch AGM in January.

Field trips have been few and far between this year but those that were held were very enjoyable and well-attended We visited Dufton with Dr Barry Butler, Thrislington Quarry with Dr Steve Maclean and Upper Teesdale with Dr Trevor Morse. We have had an enjoyable, if somewhat wet, weekend in Keswick with Mervyn Dodd.

We have started to hold DIY days where we take a local field guide book and go and look at the exposures for ourselves. These have proved to be very popular and have been the source of much discussion (and amusement).

The branch is now getting back on its feet and we have a good mix of field trips and DIY days planned for 2003 as well as weekends in Skye and Edinburgh. We are also looking forward to hosting the Symposium next year and I would like to take this opportunity to thank all those members of the symposium committee who have put in much time and effort in ensuring that it will all run smoothly and successfully.

Finally, on a sadder note, I would just like to pay tribute to Arthur Forsey who died this year. Arthur was one of the first OU students to gain a BSc. (Open) as opposed to the BA, which had previously been awarded to both Arts and Sciences degrees. He joined OUGS in the early 1980's and was a mainstay of Northumbria branch (or South Durham branch as it was known then) and will be sadly missed.

James Gallagher

Oxford

The membership is now at about 110 which is a slight increase on last year and many of our members take part in the varied programme of lectures, day trips and weekends away.

Our AGM was held in January at "The Spotted Dog" near Newbury and this was followed by a talk and slides by John Downes about his recent trip to New Zealand which incorporated both the geology and wildlife of the country, not forgetting the wonderful scenery. This was followed by the second annual dinner. The February lecture was held at the University of Reading when Chris Green of Royal Holloway College gave us a most interesting talk on the Geology and Provenance of the Stones at Stonehenge.

We had our first field trip of the year on 24 March, a day trip to the Dorset coast with John Chaffey. There was the opportunity to blow away the winter's cobwebs with a walk along the coastal footpath looking at the Portland Limestone. The next trip was another day trip on 14 April, again to Dorset, but this time to Overcombe, Bowleaze and Redcliff Point with Alan Holiday looking at the Oxford Clay and the Corallian Sandstone up to the Trigonia Beds. A very enjoyable day out with excellent weather. At the end of April we used Grange-over-Sands, Cumbria as a base for studying the Dinantian, Martin, Urswick and Park limestones with Murray Mitchell, a trip that was postponed from the previous year due to foot and mouth disease. A most informative, and occasionally challenging, weekend.

On a beautiful day in June we had a trip to the Cotswolds looking at limestones of the Middle Jurassic with Dave Green. Another interesting day with another challenge. At the end of June we went to Norfolk to look at Ice Age features and deposits with Dr Jill Eyers which included a video of the excavation of the remains of the West Runton Elephant at Cromer Museum. Other localities included Overstrand, Happisburgh, Blakeney Quay and West Runton where various features of glacial geology could be seen. A very interesting visit to a fascinating area.

On Tuesday 24 September we were back in Reading for the third John Souster Memorial Lecture by Professor Bill Challoner of Royal

Holloway College on Carbon Dioxide and the Evolution of Plants. A very interesting talk which was well attended.

The final field trip of the year is the Winter Weekend in Torquay with John Mather which is to be held on the second weekend in November. We also have the Christmas Lecture to look forward to in Oxford, this year on Planetary Geology by Monica Grady, which will be followed by our Christmas Party.

Our thanks go to all the leaders and lecturers who have kindly given their time and services and to all the Committee members who have worked hard behind the scenes to organise the various events and ensure that you receive your newsletter in time to attend. All these contributions have ensured the continued success of the Oxford Branch.

Sally Munnings

Severnside

The AGM was held in the Icons Suite at the National Museum and Galleries, Cardiff, on February 3rd 2002. After the business of the meeting Dr Douglas Bassett, the former Keeper of Geology at the Museum, gave us an entertaining talk on the early 19th century geologist and divine Archdeacon W D Conybeare. We were sad to lose Jan Ashton-Jones as Branch Organiser as she had become National Events Organiser, but she has assisted the new Branch Organiser, Philip Clark. Bridget Wood was re-elected Treasurer and has kept the books most efficiently and the rest of the committee have been consulted from time to time.

We produced our Newsletter, Sabrina Times, in December 2001, and January, April, June, September and October 2002. These have not only given advance notice of our programme and write-ups of a number of our activities and of members' geological visits, but have been diversified with "Trilobite Hash" cartoons by Liz Edmundson and with geological quotations, website references and, recently, a Geological Word Search.

As usual, the first field trip under the branch's aegis was that to Tenerife taken by Jan Ashton-Jones and Linda Fowler, at the end of February and beginning of March, and they also organised trips to Brittany granites in May (with Joe Jennings as leader) and to the Caledonides of Norway in July (with Mark Anderson as leader).

The Introductory Day was held once again at Upper Soudley in the Forest of Dean on March 17th, with Dave Green leading; a good number attended including friends from another branch. After that we favoured South Wales for four field trips running. On April 14th the venue was Blaen Onneu Quarry in the Carboniferous Limestone south of Crickhowell, Paul Wright leading. On May 26th Alan Cuthbertson showed us, and friends from the GA, the Darell open cast coal site between the upper Swansea and Neath valleys with spectacular fossil trees. On June 23rd Geraint Owen repeated last year's traverse of the Black Mountain (quite a few members who had missed it were glad to descend from the Farewell Rock to the top of the Old Red) and on 8th September John Davies showed us the Triassic Unconformity first at Ogmore and then at Barry Island. We returned to England on 20th October when Eric Robinson explained the building stones of Gloucester Cathedral and precincts in his inimitable style.

Our day of lectures was held again in the Icons Suite at the National Museum and Galleries, Cardiff, and we are very grateful to Steve Howe for his helpfulness with our meetings in that extremely attractive venue. Professor Adam Schulz gave us a first hand account of deep sea hydrothermal activity (he journeys in Alvin as you or I would in the Inter-City to Paddington), Jenny Pike gave a fascinating talk on what she deduces from the diatoms she finds on her trips to the Antarctic about ocean history and climate change, and Linda Fowler took us much further back in time and securely on land to the Norwegian Caledonides.

Some maps have been added to the collection which makes up the bulk of the Branch Library; the policy is to do so every time we go to an area where we have not got the relevant geological maps.

Philip Clark

South East

With the January AGM over, the atmosphere changed to being hot and sultry, courtesy of Heidi Barnes. She has a habit of increasing the temperature wherever she goes! Transporting us to Hawaii, using audio and nearly risqué visual props, we gazed with wonder at the stunning and prize-winning slides of her field meeting to these volcanic isles. The heat was again increased in the local Indian Restaurant for our annual dinner.

The highlights of our visit 'Behind the scenes' at the Natural History Museum were: the newly acquired specimen of beryl from Afghanistan, which cost £8000 (well worth it in my opinion); a HUGE thinly-sliced stony meteorite, so thin that the enclosed olivines were transparent; a purse made from asbestos and a just divine sample of proustite, a silver arsenic sulphide collected by Victorians from South America.

Dr Gareth George of Greenwich University, guided us around the sedimentary exposures at Eridge, Harrison's and Bowles Rocks near Tunbridge Wells. We measured palaeocurrent directions, found evidence for tidal activity and whether or not the sands were deposited in incised valleys. Some of us attempted to use our compass clinometers but with not much success. Will I ever get the hang of them and would the angles on a sheet of paper mean anything anyway? I am ashamed to say that the answer has to be NO! There is a part of my brain which doggedly denies either any previous knowledge of mapping, or ever using a clinometer, in the last 20 years.

The impression gained from visiting Darwin's Down House was of his dogged determination, despite a debilitating illness, and his kind, unassuming character. He must be an inspiration to us all.

We visited Cuckfield and Horsham Museums in November. Cuckfield houses a small collection of local *Iguanodon* finds and has a display about Gideon and Mary Ann Mantell and their discoveries. We benefited from Bryan Cox's immense knowledge as he showed us around. A first edition of Mantell's book 'The Fossils of the South Downs' with beautiful illustrations by his wife Mary Ann, is at the Museum, the preface of which contains a Gideon apology for the quality of his wife's sketches! The newly erected monument to Mantell on nearby Whiteman's Green, is placed on the covered remains of the quarry where Mantell made his famous discovery of *Iguanodon* in 1822, then only the second dinosaur known to science. Mantell also identified *Hylaeosaurus*, *Megalosaurus* and *Pelorosaurus* in quarries on this site.

Our two residential field meetings were to the Forest of Dean in October and to the Tayvallich volcanics, Argyll in June. Dr Nick Chidlaw was our leader to the Forest of Dean where we found dolomitised and haematised limestone, palaeokarstic surfaces and soils and a periglacial block-field amongst the Devonian and Carboniferous sediments.

The Tayvallich event, led by Martin Howard, was certainly one of the best meetings I have attended with the OUGS: the weather - glorious, the rocks - quite fascinating, the leader - inspirational, the hotel - perfect for us, meals - overlooking Loch Fyne, company - what can I say - we bonded well; I could go on ...

At the north end of the Mull of Kintyre the Caledonian trend of the Dalradian rocks is quite obvious when looking at a map and has influenced the coastal form and road directions. The Dalradian studied was the Upper Argyll Group, particularly the Tayvallich Volcanic Formation, slates and limestones. Some of the very best pillow lavas with concentric rings of vesicles were preserved, looking as if they were Tertiary by their incredible state of preservation. I thought basalt was supposed to weather quickly! We became quite adept at spotting Tertiary dykes or so we thought. My acid bottle came out again as we gathered around an exposure. It fizzed - a limestone dyke - a scientific phenomenon! Lesson - don't interpret an exposure from a distance.

I would like to express my most grateful thanks to our leaders and to the participants who make the meetings so enjoyable. The Branch Committee must also be thanked for all the help and advice during the year including Linda Beer who has developed our web page.

Yvonne Lewis-Cutt

South West

In January the Branch AGM was held, as usual, in the Loft at Cotehele Quay. Mike Hermolle remained as Branch Organiser and Angela Scarrott was a willing volunteer for Treasurer. Before the AGM, Gordon Neighbour and Jane Anderson gave us an overview of their research (partly funded by an Ian Gass Bursary) into multi-phase dyke intrusion into the sediments of Cawsand.

In February Linda Fowler led her annual "Volcanoes on a Shoestring" trip, jointly with Jan Ashton-Jones of Severnside, to Tenerife. This has now become a regular feature on the calendar and must rank as the field trip that has had most participants. We lost a field trip to explore the Boscastle Nappe due to illness; in the event, the weather was so bad that the coast would have been dangerous.

Early in March, Mark Anderson of Plymouth University led us on an inspired tour of the Start Bay area beginning in Plymouth and finishing at Hope Cove. This gave participants an opportunity to examine, and have explained, some fundamentals of structural geology on scales from the local to the regional. This trip resulted in an excellent trip report by Penny Frost, who supplied her own well-drawn diagrams. Mark is an excellent leader and the trip deserves more time. The Annual Open/Introductory Day at Cotehele saw the arrival of a few newcomers; we even managed to attract one or two members of the public visiting the estate. Our scheduled speaker for the afternoon had to pull out at short notice due to an overseas commitment but John Macadam proved an excellent stopgap with a brief presentation on RIGS.

In May our S260 day, which had run for a number of years, was converted to a pre-SXR260 weekend (the S260 Practical Geology Weekend) and went ahead with great success with 18 participants who were not only S260 students but also others keen to improve their knowledge and mapping skills. The weekend was very much 'hands on' and aimed to provide the opportunity to become familiar with igneous (volcanic) and metasedimentary rocks and tectonic structures within them and also to gain experience in the recognition and description of sedimentary structures in the field. The evening session on Saturday allowed participants to consolidate their learning with a discussion on coastal geology. This was another trip that resulted in a well-produced trip report. These are always useful if you want to develop your understanding of the subject.

Our 3rd Level trip in June was run by Gordon Neighbour as a single day looking at the sediments in the Beer and Seaton area. Next year we plan to combine this with a hard rock day to make a 3rd level pre-summer school weekend. We had a quiet summer with no planned field trips, although several of us carried out our own individual forays. The 2002 Symposium at Norwich in July attracted a greater number than usual from the South West, we even managed to fill a table at the Dinner! Our new Treasurer, Angela, was moved enough to provide a short written piece on her first experience of Symposium.

September saw our Revision day at Saltash School, ably led by Gordon and Linda. This seems to go down well and it is useful knowing where gaps in students' knowledge occurred in previous years. Discussion during this day has led us to offer a thin section day next year.

In mid-November, I led a Geowalk from Perranporth to St Agnes as a follow-on from my Cornubia and Journal contribution. Despite it being a cold, damp and windy day, we all enjoyed the trip, learned something new and generated several new questions. The walk deserves a repetition in the summer next year. Late changes meant the loss of our visit to the Bovey Basin to have a look at industrial geology; this is postponed to 2003.

Our final event of the year will be a "Seasonal look at the Lizard Ophiolite" led by Robin Shail of Camborne School of Mines, which is planned to be an overview of the development of the Ophiolite (incorporating latest models). At the last count, Branch membership stood at 138 Full and Associate plus 31 Family.

Mike Hermolle

Walton Hall

This year we said goodbye to Tom Miller, our newsletter editor for 7 years, and John Barrett our treasurer for 5 years. Tom Duff elected at the AGM, replaces John as treasurer. Brian Cookson is now trying out the editor's chair for size and has been co-opted onto the committee until the AGM in 2003 when he will consider standing for election. Thanks go to Judith Kelly and Jenny Forrest for stepping into the breach and helping produce the May and August issues of our newsletter.

The Branch dinner was held at the Carriage House near Hitchin this year, coming south after several years in the north of our region. Drs Dee Edwards and Dave Williams were both invited as guests; these are two people who have always supported the branch most generously over the years, leading field trips, giving talks, and donating raffle prizes for branch fundraising. Tom Miller and John Barrett were also invited as guests.

We started our year of talks in January with Dr Jill Eyers who took us on a "Geological tour of the UK", stepping in at the eleventh hour when the speaker booked had to cancel. Jill has a wonderful collection of slides which cheered the winter gloom and tempted us to plan lots of visits to our own geological heritage. In February, we had the Branch AGM, followed by a splendid talk by Prof. Bob Spicer on "Plants and Climate: Recent Contributions to Earth System Sciences". This was beautifully illustrated by pictures of plant fossils, taken on a recent trip to Tibet. Considering that the fossil site was half way up a scarp face, in what appeared to be the middle of nowhere, it is amazing that they were found at all. In March we were back in the far east with Dr Tom Argles who talked of "Shuffling the Pack: the Last 60 Million Years in the Himalaya", which he assured us was not all personal experience! Again, this was illustrated with some wonderful slides that left us all wanting to rush out and book a flight. In April we moved from huge landscapes to microscopic organisms, when Marcus Gelsen of the Natural History Museum talked about Coccolithophorids and showed us some amazing photomicrographs he had produced with a scanning electron microscope. In May, Professor Peter Doyle entertained us with "Geology and the Great War"; tales of a few men in a hut vs the might of a battalion of German geologists. It has to be said that the men in the hut were Officers and Geologists, but they directed the operations in terms of where to dig trenches, and saved many lives by digging in the right places - whilst the German geologists were hamstrung with red tape. In June we moved on to Volcanics with a talk by Kirti Sharma, a PhD student within the Earth Sciences Department at the OU, who presented "Lava flows & Volcanoes of Hawaii". Kirti stepped in at the last minute when Dr Andy Harris of the OU and University of Hawaii had his trip to the UK curtailed this year and could not talk to us as arranged. In September I showed slides of New Zealand, taken on the GA trip in November 2001; Prof. Steve Self helped out with pronunciations of the Maori names for the various volcanoes and fielded all of the difficult questions about the geology - thank you Steve. In October we went for "Something Completely Different" with a talk from Landscape Photographer Derek Dewey-Leader. We all take photographs on field trips and Derek inspired us with some beautiful landscapes of mountains, as well as some different views of rock formations. In honour of our geological interests, he had selected as many photographs as he could of rock formations and said he was surprised how many he had got when he really looked at them. Most interesting was the discussion that ensued on the relative merits of digital photography. Let us hope the photographic competition benefits from this deviation from our normal fare. In November, the talk on "The Geology of the Chilterns" by Dr John Catt provided some useful background to Mike Henty's "Day Out in Buckinghamshire" (see below), where we saw both what we have locally and heard how it got there.

Our field trips this year started in the Forest of Dean in February, where Dr Clive Roberts and Dave Green, led us on stratigraphy and mapping exercises on the Forest of Dean Syncline. The weather on the first day was crisp and cold but the mapping exercise was enthusiastically carried out along a disused railway track. The stratigraphy exercise started enthusiastically in the Edge Hills sand quarry but the zeal gradually diminished

as persistent rain turned logging sheets to pulp! A really good 'back to basics' weekend for the experienced and inexperienced alike. In April, Professor John Mather led us on a day trip to the Isle of Sheppey where we studied coastal erosion and the mineralisation of the London Clay. The sun shone, the mud wasn't too muddy, and we found just about every fossil type in the book - what more could you ask from a field trip? At the end of June, Mike Henty led a "Day Out in Buckinghamshire" where much of the local geology can be deduced from building stones. Outcrops and landforms were inspected at Pitchcott Hill Farm and the effects of glaciation were observed from the top of Coomb Hill.

During the year many branch members and committee members were heavily involved in the organisation of the Annual Symposium, held this year at UEA in Norwich. East Anglia Branch helped out at the event itself and it was a great weekend. A superb effort from all concerned.

Linda McArdell

Wessex

We have remained very active over the past year in organising a wide variety of field trips and events throughout the UK and strengthening our ties with other geological groups and societies. In particular the number of weekend trips has increased through the excellent work of Debbie Tabner and Sheila Alderman who continues to present the branch members with a full and well-planned programme of day trips as well.

Our highlights have been a trip to the Forest of Dean, led by Dave Green, where we went underground in Hopewell's Colliery show mines and Clearwell Caves. Sheila played attendees off against each other to make sure everyone plucked up the courage to go caving (I will if you will!). Debbie's week long event based in the Kindrogan field studies centre led by Rosalind Garton was memorable for some wonderful Scottish scenery and geology but not least for the quality of our evenings self entertainment. Colin Morley's sign-interpreted performance of Macbeth reduced himself to a state of exhaustion and everyone else to helpless tears of laughter.

A recent, stormy, weekend in Cornwall with Alan Holliday of Weymouth College, meant that we had covered almost the whole length of the country, while Steve Warren's trip to Cumbria followed by Norwich Symposium, accounted for most of the breadth! Peter Martin took the additional financial accounting generated by this increased activity in his stride.

We were especially pleased to welcome our friends from La Societe Guernesiaise to Dorset's shores in April. Steve Etches' Kimmeridge Clay fossil museum and John Chaffey's walk in gloriously sunny Purbeck, rendering them suitably gob-smacked and breathless! We were also pleased to share John's celebration of his 50 years as a geologist in June and marked the occasion with a small gift in recognition of his support to the OUGS over many of those years.

West Midlands OUGS members and guests weren't quite so lucky weather-wise in November, but hopefully went home with a few local fossils in amongst the mud they collected. I have to say, I have never seen such a clean group; the state my boots and clothes were in, I scarcely believed we went to the same place. Although a more sociable and tuneful group of Geologists you couldn't wish to meet!

Our well established S260 introductory day and AGM lecture events continued to draw good numbers and once again the efforts of our diligent branch officers and volunteers has been rewarded by high attendances and appreciation of the membership.

We are delighted that Symposium 2004 will be centred at Canford School in Dorset. The many facets of organising the event are already underway to ensure that the exemplary standards of the event are maintained. Very well done to the Norwich Symposium organisers and good luck to Durham 2003, but don't make it too hard an act for us to follow!

Our Newsletter, Wessex Footnotes, is well supported by members and guests who provide excellent articles for Alf Tingey to edit and put together in consistently full editions. Chris Phillips contributes to publicising our activity to a wider audience via our interesting and regularly updated website. The facility for colour photographs to complement the articles makes the site a good source of recruitment of new members. Linda Morley and Debbie managed to restore calm on our stand at the Dorset Fossil & Mineral Fair in Wimborne, after I brought the whole lot down trying to add finishing touches to the very top! They recruited a couple of new members and generated some interest in OU study materials.

Our loyal and precious band of leaders was sadly reduced on the death of Professor Michael House in the summer. He will be long remembered for his kindness and enthusiasm towards the OUGS, other geology groups and, of course, the legacy of his books and other written contributions to Dorset geology. He epitomised all our leaders in the selfless giving of his time and energy. Perhaps our best tribute will be to continue to foster a love and joy of discovering geology in the field.

Thank you to everyone who has served the OUGS in the past year and in particular the membership of Wessex Branch.

George Raggett

West Midlands

Welcome to this my first report as a full branch organiser. May I first thank the branch committee for their help and support throughout the year, secondly my thanks go to the national committee and the other branch organisers for their able assistance as well. Thanks must also go to the field trip leaders who led the West Midlands branch trips this year.

After the debacle of last year, this year has been a rather good one for the West Midlands. A total of nine events took place between January and November, all well attended, especially the longer weekend trips (the last one to Dorset in early November had 27 people present on both days).

We tried something different this year by holding our annual day of lectures back to back with our S260 field trip over a weekend; this seems to have worked quite well with both days proving of interest to members.

We held a further three one-day trips to Charnwood, Trevor Rocks and Bonsal. The one to Charnwood was run jointly with the North Staffordshire Geological Society, which has led to a further fieldtrip being jointly organised for next year.

We also undertook three weekend trips to Cumbria, Anglesey and Dorset. These went really well and were enjoyed by all (many thanks must go to Alun Davies, Terry Whitburn, Ian Kelly and Chris Tompkins for leading the traditional singing that the West Midlands like to encourage on fieldtrips). An interesting point to note is that on these trips nearly half the people attending were from other branches; this would seem to validate the importance of the events diary in the national newsletter.

Now to the future, the branch committee has decided to try to have at least one event per month next year. We have also decided to join the modern world and set up a website for 2003. Membership this year has increased in large part thanks to a program of committee members attending Earth Science tutorials in Birmingham to advertise the OUGS in the West Midlands. Next year we hope to improve on this style of recruitment by increasing the number of venues in the region where committee members attend. On the whole the West Midlands are looking forward to a great 2003.

Chris Gleeson

West of Scotland

Events kicked off this year with our AGM in January which was held in the committee room of Borders Bookshop, Glasgow. As always we had a lively discussion on Branch matters and I must commend all attendees who managed to stay awake during the proceedings. We welcomed Alison McMenemy as our new Events Officer, and Maureen van Stratum as Web Slave. Hammy Corrance gave us a very interesting talk on his discovery of *Chirotherium* trackways on the west coast of Arran. As a way of paying tribute to the memory of Lindsay Hamilton, our late events officer, we decided to introduce a Memorial Prize to be presented annually to the person who had made the most significant contribution to the branch during the previous year. Jane and Maureen volunteered to seek out and design something suitable. After the meeting we all regrouped at D'Magios Italian restaurant for an excellent meal.

The first event in our calendar was in May, a week-long exploration of the geology of the North West Highlands with Dr Iain Allison of Glasgow University which Jane had kindly agreed to re-run after the disappointment of cancellation in 2001 due to the foot and mouth epidemic. This turned out to be a great week with seventeen members attending and the weather being uncommonly kind to us. We managed to take in most of the geology lying between Torridon and Durness; an account of the week's goings on will appear in a future edition of the OUGS Journal.

The Geology of the Isle of Arran (Scotland in Miniature) was our next outing, and this weekend trip, led by Dr Stuart Monro in June, brought home to us the significance of Arran as the geologists mecca. We even survived the 2 mile 'assault course' of the Fallen Rocks on the NE of the island, where large masses of conglomerate had fallen from the cliffs and obliterated the coastal shelf. The reward for this was Hutton's 'other' unconformity near Lochranza.

Meanwhile, whilst all us other committee members had been out enjoying ourselves, Alison had been toiling away organising trips to the Ballantrae complex with Dr Keith Ingham in July and the Fife coast with Dr Adrian Finch in October. The post-exam weekend in November to Knapdale, again with Dr Iain Allison, was very enjoyable and again we had a good turn-out. Classic pillow lavas, interesting sedimentary structures, the Crinan Grits and the Tayvallich limestone were just some of the localities visited. Our turn-out for trips this year averaged 19% which is quite good, but a significant number of those who turned up on field trips were members from other branches.

Branch finances are in a healthy state at present, thanks to Susan's efforts, and Alison has introduced a fresh flood of new ideas during her first year in events. I know from experience that this can be one of the most difficult, yet rewarding, jobs and in many ways 'hands on' geology is what the Society is all about. Next year's program promises to be even better. Trips in the planning stages include Kirkcudbright in south west Scotland and the Outer Isles with possibly a visit to St Kilda. Jane has done a great job this year giving the newsletter a new look, with the introduction of good quality photographs and providing the opportunity for members to receive their copies via e-mail, not to mention the excellent job she did in organising the NW field trip in May. Maureen and Theo have been busy behind the scenes maintaining the branch website, keeping it lively and interesting with plenty of photographs and news articles.

My thanks go to all our committee members for getting their heads down and getting stuck in this year, helping our branch to flourish. More remarkable is the fact that, along with doing their respective jobs, most of our committee were also taking courses.

Stuart Fairley

Yorkshire

Our year started at the AGM in January with a talk from Roger Osbourne author of The Floating Egg (about the alum industry on the Yorkshire coast) who talked about some of the problems he has come across whilst investigating and writing his books. In February our winter weekend was on the coast at Whitby. This turned out to be even more exciting than the St Hilda's snakes (ammonites) and local jet could provide. The guide's dog got stuck on the cliff together with the guide who had gone to the dog's rescue, and the local coast guard was sent for!

In April the snow greeted us in Wharfedale when we accompanied Alan Stollery from Kettlewell up Dower Gill on the flanks of Great Whernside to look at and discuss the structures in the local geology. In May we joined with the East Midlands Branch to go to South Ferriby and the Humber estuary. In the late spring Bank Holiday a group went gold panning at Leadhills, just after a gold nugget had been found.

On 1st June we visited Branshaw Quarry near Keighley which processes building stone mainly for sills and lintels. In the quarry face we could see river channels and deposition features. We also found fossilised wood, probably washed down in floods; fascinating, but not much use for building stone. We then went to see some local stone being prepared at the stone yard. In July we joined with the Northwest Branch for a visit to the Carboniferous in the Malham area.

Over the summer Bank Holiday some of our members helped at the GA Earth Alert event in Scarborough for a couple of days. Also in August we continued looking at the Pennines with a visit to the Dent fault in Sedbergh with Alan Diggles and followed the Sedgewick trail. In September we looked at the coal measures near Penistone, further south in the Pennines with Janice Doherty, one of our members. In October we continued looking at the industrial side of Pennine geology with a visit to the lead mining remains in the Hebden and Grassington Moor area; this time we were by the Craven fault and could see the limestone reefs south of the fault.

In December we will finish the year with a look at the Victorian cemetery and botanical gardens in Sheffield with Jean Sampson.

I would like to thank all our leaders for the work they have put in to making our field trips interesting and enjoyable throughout the year.

Barbara Norton

Book reviews

Precambrian Rocks of England and Wales by J N Carney, J M Horlack, T C Pharaoh, W Gibbons, D Wilson, W J Barclay, A R E Bevins, J C W Cope & T D Ford, 2000, Joint Nature Conservation Committee, 252pp, £53.00 (hardback), ISBN 1861074875.

This is a book for someone with both a theoretical and practical interest in the subject. It takes a close look at some of the outcrops of Precambrian rocks which have been proposed as SSSIs, in particular in Charnwood, North Wales, Shropshire, Malvern and the Welsh Borders. In fact, the book is one of the Geological Conservation Review series whose aim is to provide a public record of the features of such sites.

Several authors have been involved and the book can be read as a series of articles. As a result, styles vary but it is generally easy to read.

The book starts with an introduction to the Precambrian rocks in England and Wales. This describes the role of fault systems in the distribution of the scattered outcrops and stresses the importance of geochemistry in recognising the different terranes into which the Precambrian basement is grouped. There is a concise explanation of the terrane concept and a summary of the plate tectonic models relating to these terranes.

Chapters 2 to 7 each describe a particular area with special reference to a number of sites. It should be noted, however, that many of the sites are privately owned and permission may be required to visit. The chapters all start with an introduction to the area, describing the history of the rocks and explaining some of the geochemistry. Detailed descriptions of each location follow, with photographs of particularly interesting sections. Additional paragraphs on interpretation put the details into context.

Chapters 8 and 9 are slightly different in that they concentrate on a subject, Palaeontology and Lower Palaeozoic rocks respectively, rather than a particular area, but the format is the same. Chapter 8 concentrates on the fossils to be found in Charnwood, but sites in Shropshire and Wales are also described.

In addition to the photographs mentioned above, there are plenty of diagrams and maps throughout. These are generally clear and a great help in understanding the information presented.

This is not a book to be read straight through. Rather it is one to consult from time to time on particular areas of interest, or before a field trip in one of these areas. After the trip, it's a fascinating book to return to, putting observations into context. Although the book is not intended to be a field guide (and it is really too big to carry around), it gives the informed reader a good introduction to the history and composition of the Precambrian rocks of Southern Britain and enables them to apply that understanding to features they come across in the field.

Patricia Thomas BSc Hons (Open)

Iceland by T Thordarson and A Hoskuldsson, 2002, Terra, 200 pp, £14.95, (paperback) ISBN 1903544068.

One of the more pleasant discussions among geologists is on the subject "if you could go on a field trip to any location in the world where would it be?" The answer of course, would depend on your particular areas of interest in the subject, whether you were fascinated by fossils, metamorphic rocks, igneous rocks, the K-T boundary etc. At or near the top of many answers would be 'Iceland', as here a mid-ocean ridge is exposed above sea-level, allowing easier study of the volcanic and tectonic aspects of mid-ocean ridge systems. A hot spot beneath Iceland has caused more eruptions than usual on a mid-ocean ridge, so has built it up above sea-level. Iceland also has the fascination of large icecaps and glaciers.

Iceland is the active part of the North Atlantic Large Igneous province, and all of its rocks are geologically very young, formed within the last 25 Ma. The climate in Iceland, and the changing climate during the Quaternary Ice Age, has had significant effects on rock-forming processes, resulting in diverse (and weird and wonderful) sedimentary and volcanic rock formations. (Just try imagining what effect an ice cover has on a volcanic eruption, for example.)

My particular interest in Iceland started, when, as a marine geophysicist studying mid-ocean ridge processes, I was on a research vessel in the North Atlantic looking at the Reykjanes Ridge, the part of the Mid-Atlantic Ridge that continues north into Iceland. This research vessel was a converted deep-sea trawler, which had a tendancy to roll and pitch with gusto in even gentle seas, and in the Atlantic gales typical of this area often made geophysical measurements impossible. We would fantasise of having a meal in which your dinner plate would stay on the table, and sleep without having to wedge yourself in your bunk with a life jacket. Research on Iceland without the disadvantages of a few kilometres of water between you and your objective (and without being seasick) seemed very attractive.

Some years later I started research on Iceland, and, probably having raved about it to OUGS members, was asked to run an OUGS trip there. As part of the planning I looked for field guides in English, and was lucky that the Geologists' Association had just published a field guide to Iceland, which was a vast improvement on the field trip notes that were all that were available previously. The GA guide was the best available at the time but had limitations; too few and poorly drawn illustrations and a few irritating errors. The new guide to Iceland by Thordarson and Hoskuldsson remedies the limitations of the GA guide. It is primarily a field guide and provides much more detail of field excursions, with good photographs and diagrams (whilst still being easily readable) and a comprehensive and up-to-date first chapter on the geology of Iceland, understandable if you have done S260. I highly recommend it if you are going or thinking of going to Iceland (even on a non-geological holiday).

Sandy Smith (M.A., Ph.D., Department of Earth Sciences, OU)

The Carbon Cycle by T M L Wigley & D S Schimel (eds), 2000, Cambridge University Press, 292pp, £40.00 (hardback) ISBN 0521583373.

This is definitely not a book for the coffee table. This is a book intended for the serious researcher and is more suited to higher degree research.

The Carbon Cycle is a collection of 21 papers mainly from American Academics – why so little from UK based research? It is set out in five main sections: three of which present papers on the themes: 'The Missing Carbon Sink' 'Paleo-CO_2 Variation' 'Modelling CO_2 Changes'

The blurb states: "… leading scientists examine how atmospheric carbon dioxide concentrations have changed in the past and how this may affect the concentrations in the future. They look at the carbon budget and the 'missing sink' for carbon dioxide. They offer approaches to modelling the carbon cycle, providing mathematical tool for predicting future levels of carbon dioxide ..."

I thought this book would be of great interest, indeed some papers do present some good back-ground reading

Penny Widdison MSc, Postgraduate Research, Durham

The Little Book of Earthquakes and Volcanoes by Rolf Schick, 2002, Copernicus Books (Springer-Verlag New York), 164 pp. £14 (hardback) ISBN 038795287X.

The author Rolf Schick is a retired Professor of Geophysics at the University of Stuttgart. He specialised in earthquake seismology and physical volcanology.

The book was originally written in German then translated into English by Peggy Hellweg. She has done an excellent job; with only a few sentences sounding a bit odd. The book is easy to read but there are no in depth discussions. There are three chapters. The first is very short and asks the question 'How solid is the "solid" Earth?' Here the ideas of the Earth's structure and plate tectonics are briefly introduced.

Chapter 2 is about earthquakes. Starting with ancient peoples mythical beliefs he proceeds to talk about the causes of earthquakes at an academic level. There are several equations of the type I would expect to see in an academic text, for example the one for seismic moment.

Chapter 3 is on volcanoes and follows a similar pattern to the previous chapter. He talks about the different types of volcanic eruptions, e.g. Effusive, and the mechanisms of eruptions. Volcanism on the planets in our solar system is compared to that here on Earth.

It is difficult to decide who the book is aimed at, not the coffee table because there are no pictures. The text, while easy to follow, for someone with geological knowledge, is not for the lay man, especially as there is no glossary of terms. The equations are, I would have thought, of academic interest only. The few diagrams are not referred to at all in the text.

Lyn Relph, BSc (Hons), Continuing Earth Science student.

Coast and Country; Geology Walks in and around Dorset (including excursions within the World Heritage Site) compiled by the Dorset Geologists' Association Group, 2003, published by the Dorset Geologists' Association Group, 208pp, £7.95 (paperback) ISBN 0954435400.

This is a book to keep with you if you are travelling in this part of the UK. It tells you why the area looks like it does, what has been happening to the bit of crust beneath your feet and how people have exploited the available resources.

The big picture of the area's geological history is well summarized. The 28 excursions focus upon different parts of this big picture and reflect their authors' interests. This has produced a variety of trips looking at building stones, fossils, geomorphology and more.

Each chapter starts with a map covering the area. The purpose of the walk is given along with practical details such as a Ordnance Survey grid reference, where to park, locations of local shops and toilets, how long the walk takes and whether the walk is strenuous and involves difficult terrain. The geological setting is explained followed by excursion details. The explanations are clear and photographs accompany the text.

The contributions to and the compilation of this book has involved a considerable number of keen DGAG members, many of whom also belong to the OUGS. The authors range from the amateur to the professor and each has an individual flavour. Every walk has been tried and tested. The final result is a book for everybody from the curious to the well-informed at a very good price. Well done DGAG.

Debbie Tabner BSc (Hons) Open

Geology of the Isle of Man and its Offshore Area by R A Chadwick and 16 others, 2001. British Geological Survey Research Report RR/01/06. 143 pp, £30.00 (paperback) ISBN 0852723954.

A few years ago, on hearing that my parents live on the Isle of Man, someone asked me how its geology was related to the Iapetus Suture. I struggled to answer, as the 'latest' comprehensive survey of Manx geology was the Geological Survey memoir The Geology of the Isle of Man

by G W Lamplugh, published in 1903 (£150 from an Edinburgh scientific book dealer!). His map (dated 1898) was reprinted unchanged at 1:50,000 scale in 1975.

However, in the last few years, much new work has been undertaken in and around the island, largely driven by the search for hydrocarbons in the Irish Sea. Modern exploration techniques, especially geophysics and drilling, have clarified offshore and onshore structure. Biostratigraphy has been used to great effect to refine the relationships between Lower Palaeozoic units as well as later strata. As a result, the understanding of Manx geology and its relationship to adjacent parts of Britain and Ireland has greatly advanced and this Memoir is a welcome addition to the literature.

The Isle of Man consists largely of Lower Palaeozoic rocks now known as the Manx Group, Ordovician (Tremadoc – Arenig) turbidites which can be correlated to parts of the Lake District and Southern Uplands. These sediments were laid down on the eastern (Avalonian) margin of the Iapetus Ocean and have undergone several phases of deformation as the underlying oceanic crust was subducted. However, one short (8 km) section on the west coast of the island has now been assigned a later, mid-Silurian (Wenlock) age as a result of biostratigraphical analysis and has been named the Dalby Group. These sediments are considered to have been deposited on both the Avalonian and western (Laurentian) margins of the rapidly-closing Iapetus. Small areas of Devonian and Carboniferous rocks are exposed in the south of the island and the whole northern plain is covered by thick Quaternary (Devensian) glacial and periglacial deposits, completely obscuring further Carboniferous as well as Permian, Triassic and Jurassic strata at depth. A number of Caledonian granitic intrusions outcrop, as well as Palaeogene olivine-dolerite dykes radiating from the Antrim lavas.

Structurally, a northwest-dipping ramp seen on magnetic and seismic data down to about 8 km depth, named the Barrule Thrust Zone, approaches the surface near the faulted boundary between the Dalby and Manx Groups. Aha! The Iapetus Suture? Sadly, probably not! The deep seismic results from the WINCH-2 profile show a significant northwards offset before the Suture itself can be seen at depth (>12 km). It remains possible (likely?) that the two are related in a ramp – flat – ramp configuration but the detailed structure remains enigmatic, as elsewhere in the Iapetus Suture Zone.

This volume is a valuable re-assessment of Manx geology and, together with its companion 1:50,000 map (Isle of Man; Solid and Drift Geology: BGS 2001, £11.00), is essential for intending geological visitors and useful reading for all those interested in the Iapetus Suture.

Paul Speak BSc Hons (Open)

The Map that Changed the World (The Tale of William Smith and the Birth of a Science) by Simon Winchester, 2001, Viking, 300pp, £12.99 hardback, ISBN 0670884073.

The Map that Changed the World is neither the most gripping of titles, nor does it hint of the joy that lies within. But it sets out how an 'uneducated' man, the son of an Oxfordshire blacksmith, who spent time in a debtors prison, and had his work widely plagiarised by the elite and 'noble' of his day, set about travelling the length and breadth of Britain, as an itinerant canal and land surveyor, set about a work of genius.

We learn how the newly formed Geographical Society shunned him, because he was unrefined, 'uncouth', and ill bread for the polite society of London. Winchester takes us though the vagaries of this man's life and career, his meetings with the 'Great and the Good', of those who were to help and to hinder his career, and the path to his eventual downfall from society and then ... well you will have to read on.

And yet this one man, with one idea, set against the received ideas of his day, travelled thousands of miles to produce the first national geological map in the world, that of England and Wales. Winchester takes us along the route of the Titfield Thunderbolt, through the Cotswold stone, up to the north-east coast at Newcastle upon Tyne, and thence across the Pennines through Shropshire and on into Wales. Sitting next to the driver and an ever-vigilant guard, wielding a blunderbuss in case of the menace of Highwaymen, we hear how this man, hammer in-hand, was ever-ready to descend to collect rocks, and fossils and make notes of his findings.

As Winchester states "the fact that a half-educated Oxfordshire yeoman, working alone, with compass and notebook and clinometer and an abiding appreciation of the beauty and importance of fossils, could summarise with such accuracy what a thousand surveyors and professional geologists in the decades since have really only succeeded in confirming, is little short of a miracle".

For me, geological maps will never be the same again, because of the work of this truly amazing man, William Smith. It put a new perspective on the use, importance and utility of the compass clinometer, and gave me a much deeper appreciation of the story of the rocks and fossils beneath our feet. It is the most enjoyable biography that I have ever read. A definite page-turner, and a great read after the OU study of the past year. An absolute must for any student of Geology past or present.

Tremaine A O Cornish, Cert (Nat. Sci.),
BA(Hons.), MSc., MPhil

Classic Geology in Europe 4 - Canary Islands by Juan Carlos Carracedo & Simon Day, 2002, Terra Publishing, 294pp, £14.95 (paperback) ISBN 1903544076.

For those travelling to the Canary Islands this book will be a welcome expansion and update of the relevant chapter in Terra Publishing's "Volcanoes of Europe" (reviewed in Journal 22 (2) Symposium Edition 2001). The book is very obviously aimed at those who will use it on the spot, with directions to locations of interest, and the handy size and strong binding mean that it can be taken into the field.

There are useful introductory chapters on the geological background and on the general environment and logistics and, since these are necessarily fairly general and could date, there is also a list of websites.

The bulk of the book however is made up of a comprehensive chapter on each of the islands and, since the proof of the pudding is in the eating, I asked our Review Officer to let me road-test this book on my recent OUGS trip to Tenerife.

The chapter has comprehensive descriptions of the wide variety of excellent exposures on the island, many of which are ones that I've visited on a number of occasions: anyone new to the island will find plenty here to keep them occupied. Our "test-case" was to find an exposure of the Mortalon, a landslip breccia on the north side of the island that had previously eluded me and, following the instructions, we were able to locate the excellent first exposure (stop 6.9) although the second proved more difficult – perhaps a convoy of 9 vehicles is not ideal for exploration? I felt a bit sorry for the fruit vendors at the end of the parking area too as we all marched past them to look at the road cut! (We did stop there on the way back to the cars though.)

These islands are also the focus of continuing research and, although there is a good list of references (up to 2002) included, if you are planning a trip you might wish to check library databases beforehand: I would recommend Science Direct via the OU Library. Readers might also be interested to know that the OU is writing a short course "How Volcanoes Work" which includes virtual field trips in Tenerife – I have seen some early versions and they are very good.

However, that is side-tracking; if you are planning a visit to the Canaries then do get this book first, it will be well worth the money!

Linda Fowler BA (Hons) Open, OU Tutor

THE CONSTITUTION OF THE OPEN UNIVERSITY GEOLOGICAL SOCIETY

1 NAME

1.1 The Society shall be known as the Open University Geological Society (OUGS) herein after referred to as The Society.

2 AIM

2.1 To promote and advance public education in the field of geology and other earth sciences. In furtherance of that object but not further or otherwise The Society shall have the power to do all or any of the following:-
(i) Promote and support local branches of The Society.
(ii) Organise symposia, conferences, national and local events.
(iii) Provide a means by which members receive information on the activities of The Society and on earth sciences.
(iv) Foster good relations with organisations having related interests.
(v) Raise funds.

3 MEMBERSHIP

3.1 Full Membership shall be open to:
i) past and present students of The Open University.
ii) academic, research, technical, tutorial and counselling, and administrative staff of The Open University.

3.2 Associate Membership shall be open to any adult person (i.e. aged sixteen or over).

3.3 Family Membership shall be open to any other named adult residing at the same address as a full member.

3.4 Temporary Membership shall be open to any adult person and shall be valid only for the duration of the event in which the temporary member is participating.

3.5 Joint membership shall be open to two full members residing at the same address at an appropriate subscription.

3.6 A member in any of the above categories shall be defined as one who has paid a current and appropriate fee.

3.7 The President and Past Presidents shall be deemed members for life of The Society and shall not be required to pay any subscription.

3.8 Honorary Life Membership may be conferred by a general meeting of The Society following recommendation by the OUGS Committee, to which body ordinary members may make recommendation.

4 SUBSCRIPTIONS AND FINANCE

4.1 The Society's year shall run from 1st January to 31st December.

4.2 The annual subscription and temporary membership fees shall be decided at the preceding Annual General Meeting. The annual subscription shall become due on the first day of the Society's year.

4.3 Subscriptions received from members joining for the first time on or after 1st July will extend over that year and the whole of the following year.

4.4 If a subscription has not been renewed by 31st March, membership shall be deemed to have lapsed.

4.5 Any member acting on behalf of The Society shall keep a record of income and expenditure incurred.

4.6 The accounts of The Society shall be subject to annual audit. Audited annual accounts shall be presented by the OUGS Treasurer to the OUGS Committee, to the Open University Students Association (OUSA) and to the next Annual General Meeting of the Society. Copies of the audited accounts shall be distributed to members not later than one month before the Annual General Meeting.
A member may request a copy of the accounts after audit has been announced in the OUGS Newsletter.
The auditor(s) for the next financial year shall be appointed at the Annual General Meeting.

4.7 The OUGS Treasurer shall present a statement to the Annual General Meeting on the current financial situation of The Society and a forecast for the coming year.

4.8 Fund raising shall be subject to the approval of the OUGS Committee.

4.9 Any university, library, organisation or society may receive any publication of The Society by payment of a fee equivalent to the current membership fee or in exchange for some similar publication.

4.10 Members of The Society may be reimbursed for any expenses incurred on behalf of The Society, but shall receive no fee.

5 GOVERNMENT

5.1 The OUGS Executive shall be responsible for the management of The Society.
The OUGS Committee shall be responsible for overall policy and for the activities of The Society's Branches.
Members of the OUGS Committee may act individually or collectively to deal with routine matters.

5.2 The OUGS Executive shall consist of the following:-
The President
The Chairman
The Secretary
The Treasurer
The Membership Secretary
The Newsletter Editor
The Information Officer
The Events Officer
plus a Branch Organiser (elected annually in June by the Branch Organisers).

5.3 (i) The OUGS Committee shall consist of the following:-
The members of the OUGS Executive
The Branch Organisers
The Sales Officer
All members of the OUGS Committee must be Full Members of The Society at the time of their election and for the duration of their term of office.
At least one member of the OUGS Committee shall be a current student of the Open University.
(ii) The Society's Representative or Deputy Representative to OUSA shall be entitled to attend meetings of the OUGS Committee, but shall not have voting rights at such meetings.

5.4 The OUGS Executive may co-opt the following post-holders:-
- a Minutes Secretary for each OUGS committee meeting and OUGS General Meeting
- a Journal Editor
- an Administrative Assistant
- a Gift Aid Secretary
- the Symposium Organiser(s)
- such other assistants as may prove necessary

These post-holders may attend OUGS Executive and OUGS Committee meetings as appropriate, but shall not have voting rights at such meetings.

5.5 (i) No one person shall hold two or more posts on the OUGS Committee concurrently.
(ii) No one person shall hold two or more posts on the OUGS Executive consecutively. Election to the position of Chairman of The Society shall be an exception.

5.6 The OUGS Committee shall invite a member of the academic staff of the Earth Sciences Department of the Open University to be President of the Society for a term of two years, commencing in even-numbered years.

5.7 The Society through the OUGS Committee shall be empowered in exceptional circumstances to offer a position of Vice-President.

6 PROCEDURE

6.1 There shall be an Annual General Meeting (AGM).

6.2 A Special General Meeting may be called at the request of the OUGS Committee, any three branches, or fifty full members. The motion(s) to be debated at the meeting must be specified in writing at the time the request is submitted to the OUGS Secretary.

6.3 General Meetings shall be conducted according to the Standing Orders for General Meetings.

6.4 The OUGS Secretary shall give fourteen weeks notice in writing to all members of the date, time and venue of any OUGS General Meeting. OUGS General Meetings shall be held at weekends or on public holidays.

6.5 (i) Any member shall give the OUGS Secretary at least twelve weeks written notice of any constitutional motion to be placed on the agenda of the AGM.
(ii) Any member shall give the OUGS Secretary at least four weeks notice of any non-constitutional motion to be placed on the agenda of the AGM.
(iii) Other matters may be placed on the agenda of any OUGS General Meeting subject to the approval of the OUGS Executive.

6.6 The OUGS Secretary shall send the agenda for OUGS General Meetings to all members at least two weeks before the meeting.

6.7 Nomination for election as Officers of The Society should reach the OUGS Secretary at least two weeks before the appropriate AGM. Nominations shall be in writing, with written permission of the nominee and endorsed by two Full Members of The Society.

6.8 Membership of The Society must be proved to gain entry to General Meetings.

6.9 Full Members may speak on motions at General Meetings and may vote. Associate and Family Members may speak on motions at General Meetings but may not vote.

6.10 Members of the OUGS Committee shall submit their resignations at the appropriate AGM, but may be eligible for re-election.

6.11 (i) OUGS Committee Members other than Branch Organisers shall serve for a term of two years, with a maximum of six years and six months in the same post.

(ii) OUGS Committee Members other than The President and The Chairman shall be elected at the appropriate AGM.
(iii) The Society's Representative and Deputy Representative to OUSA shall be elected at the appropriate AGM, each to serve for a term of two years.

6.12 The Secretary, the Membership Secretary, the Information Officer and the Society's Representative to OUSA shall be elected at the AGM in even-numbered years.
The Treasurer, the Newsletter Editor, the Events Officer, the Sales Officer and the Deputy Representative to OUSA shall be elected at the AGM in odd-numbered years.
Individual elections to be in the order given above.

6.13 (i) The Chairman of The Society shall be elected by the OUGS Committee from amongst members who have served on the OUGS Committee for a term of office during the previous five years. The election shall take place in odd-numbered years.
(ii) Nominations for the post of Chairman of The Society shall be made in writing by members of the OUGS Committee, to the OUGS Secretary at least two weeks before the meeting of the OUGS Committee at which the election of the Chairman is to be held.
(iii) When a vacancy occurs by resignation, disqualification or death of the Chairman of The Society, a new Chairman shall be elected at the next OUGS Committee Meeting, pending which the OUGS Secretary shall assume the responsibilities of the Chairman.

6.14 Members of the OUGS Committee, other than the President, the Chairman and Branch Organisers, shall be elected by single transferable vote of Full Members present at a General Meeting of The Society.

6.15 When a vacancy occurs by reason of resignation, disqualification or death a replacement shall be appointed by the OUGS Executive to fill the vacancy until the next General Meeting, when the replacement shall retire, but may stand for election for the next or remaining term of office.

6.16 The Society's Constitution may only be amended at the OUGS AGM or at a Special General Meeting called for the purpose. A two-thirds majority of those present and eligible to vote is required for such amendments. No alteration may be made to the Constitution(s) which would cause the Society to cease to be a Charity at Law.

6.17 All other voting decisions shall be by simple majority.

6.18 The Society may be dissolved by consent of two-thirds of those present and eligible to vote at a Special General Meeting called for that purpose. If upon winding up there remains after the satisfaction of all debts and liabilities any funds whatsoever the same shall not be paid or distributed amongst the Members of the Society but transferred to some other society or societies having objects similar to those of The Society and if and so far as effect cannot be given to such provision then to some charitable object, that shall include OUSET (Open University Students Educational Trust).

7 BUSINESS

7.1 The OUGS Committee shall meet at least twice a year, once immediately before the AGM.

7.2 A quorum of eight, five of whom must be Branch Organisers, shall be required at an OUGS Committee Meeting with at least one of the following present: Chairman, Secretary or Treasurer. A quorum of four shall be required for an OUGS Executive Meeting with at least one of the following, Chairman, Secretary or Treasurer.

7.3 The OUGS Committee shall be empowered to appoint Special Committees whose objectives and reporting dates shall be defined in writing by the OUGS Committee. All members of The Society shall be informed of the formation and objectives of any such committee at least fourteen days before the reporting date.

7.4 Minutes shall be taken of all OUGS Executive and OUGS Committee Meetings and copies circulated to OUGS Committee Members.

7.5 The minutes of any OUGS General Meeting shall be published in the next possible newsletter of The Society after the meeting to which they refer.

7.6 The OUGS Committee shall maintain Guidelines for the operation of The Society. Such Guidelines shall be available to members of The Society.

8 LIMITATIONS

8.1 The name or any logo of The Society may not be used without the permission of the OUGS Executive.

8.2 The Society cannot accept liability for the costs of any damages, fire, theft, legal fees or injury incurred by the activities of individual members.

8.3 The OUGS Committee shall have the right to suspend or expel any Officer, OUGS Committee Member, Full, Associate or Family Member acting against the aims of the Society after full consideration of the case. The member shall have the right to present a case, or a subsequent appeal, to the Committee either orally or in writing. The case or appeal may be presented by any person of the member's choice. Any member so treated shall have the right to appeal to The Society at the AGM following.

8.4 The OUGS Committee reserves the right to refuse admission to any applicant for membership who they have reason to believe is unsympathetic to the aim of The Society or the interests of its members or is liable to bring The Society's good name into disrepute. Any such person refused membership shall have the right to make representation orally and/or in writing and to be represented by any other person of their choice. Anyone refused membership by the OUGS Committee may appeal against the decision to the President of The Society.

9 INTERPRETATION

9.1 Any matter of doubtful interpretation, or not provided for in the Constitution shall be dealt with by The OUGS Executive pending endorsement or otherwise at the next General Meeting.

As amended at the AGM of the Society 23 November 2002.

BRANCH CONSTITUTION

This Branch Constitution will be used in conjunction with the Constitution of the Open University Geological Society

1 NAME

1.1 The Organisation shall be called the ..... Branch of the Open University Geological Society.

2 AIMS

2.1 (i) To further the object of The Society in advancing education.
(ii) To provide a local means for forwarding the aim of the Society.

3 MEMBERSHIP

3.1 Membership shall be open to all members of The Society who are best served by the ..... Branch, or who have chosen to be allocated to that Branch.

4 FINANCE

4.1 Any Branch Member shall ensure a record is kept of any monies expended or received on behalf of the Branch.

4.2 The Branch Treasurer shall present audited accounts to the Branch AGM. A copy of these accounts must be sent to the OUGS Treasurer within four weeks of audit.

4.3 The Branch shall have the power to raise funds from any sources approved by the OUGS Executive.

5 GOVERNMENT

5.1 The Committee shall consist of:-
- the Branch Organiser
- the Branch Treasurer
- other Committee Members, one or more, as required

5.2 The Branch Organiser, the Branch Treasurer and at least one other Committee Member must be Full members of The Society at the time of their election and for the duration of their term of office.

5.3 (i) No member shall hold any other post on the OUGS Committee at the same time as that of Branch Organiser.
(ii) No member shall hold the post of Branch Treasurer at the same time as that of OUGS Treasurer.

5.4 The Branch Organiser shall represent the Branch at The OUGS Committee or, if absent, must nominate a Branch Committee member as deputy who shall not otherwise be a member of the OUGS Committee.

6 PROCEDURE

6.1 There shall be a Branch Annual General Meeting. Minutes must be kept and a copy sent to the OUGS Secretary and the OUGS Treasurer within four weeks. (NB Branch Grants may not be paid if this and 4.2 are not complied with).

6.2 Branch General Meetings shall be conducted in accordance with Standing Orders for General Meetings Addenda 1.

6.3 The Branch Organiser shall ensure a minimum of four weeks notice in writing is given to Branch Members and the OUGS Secretary of the date and time and venue of the Branch AGM.

6.4 All members of the Branch Committee shall retire at the Branch AGM but be eligible for re-election.

6.5 A special Branch General Meeting may be called at the request of 10% of the members, or five members, whichever is the greater, or by the Branch Committee or by the Branch Organiser.

6.6 Within two weeks of receipt of notice of a request for a Special Branch General Meeting, the Branch Organiser shall give not less than three and not more than five weeks notice in writing of the agenda to all Branch Members, and to the OUGS Secretary, giving the date, time and venue of the meeting.

6.7 Every field trip, lecture or other gathering shall be considered a Branch Meeting.

6.8 In the absence of the Branch Organiser, a Chairman shall be elected from

among the members present at a Branch Meeting if business is to be conducted formally.

6.9 A Branch Constitution may only be amended with the approval of the OUGS Committee before being amended formally at the next General Meeting of the Society. No alteration may be made to the Branch Constitution which would cause The Society to cease to be a Charity at law.

DISSOLUTION CLAUSE

If upon dissolution there remains after satisfaction of all debts and liabilities any assets whatsoever the same shall be given to the Open University Geological Society or if that body has already been dissolved then to some charitable object which shall include OUSET.

As amended at the AGM of The Society 23 November 2002.

STANDING ORDERS FOR GENERAL MEETINGS OF THE OPEN UNIVERSITY GEOLOGICAL SOCIETY

1 QUORUM

a) A quorum of twenty five Full Members shall be required of whom at least ten shall not be OUGS Committee members.
b) If a quorum is not present within one hour after the time appointed for the meeting to commence, the meeting shall be dissolved.

2 AGENDA

a) The agenda shall be prepared by the Chairman and the OUGS Secretary.
b) Items not on the agenda may be introduced for consideration after business on the agenda has been completed.

3 THE CHAIR

a) The Chairman of The Society shall take the Chair.
b) If the Chairman is absent the President of The Society or another member of the OUGS Executive shall deputise.
c) The Chairman shall be responsible for the conduct of the meeting.
d) All business shall be addressed to the Chair.
e) Should the Chairman wish to participate in a debate, the Chair shall be surrendered to the President or other agreed deputy for the duration of that debate. The person occupying the Chair may not participate in any debate.
f) The Chairman may call attention to irrelevance, repetition, unbecoming language or any breach of order on the part of a member, and may direct the member to discontinue. In the event of persistent disregard for the authority of the Chair, the member shall retire for the remainder of the meeting.
g) The Chairman's decision on the interpretation of the Standing Orders, and on any point of order not provided for by the Standing Orders, shall be final.

4 RULES OF DEBATE

a) The Chairman shall decide the right of priority in speaking.
b) No speech shall occupy more than three minutes without the consent of the meeting.
c) A motion or amendment shall be proposed and seconded by a full member.
d) The proposer shall have first speech, after which the motion or amendment shall be open for debate.
e) No member except the proposer may address the meeting more than once on any one motion.
f) Once open for discussion a motion may only be withdrawn with the consent of the meeting.
g) The proposer of the motion shall have the right to sum up on the debate immediately before the vote is taken. The proposer may waive the right absolutely or in favour of another person.
h) No new information shall be introduced after the summing up has begun.
i) There shall be only one motion or amendment before the meeting at any one time.
j) Amendments to any matter on the agenda may be accepted up to the commencement of the meeting, subject to (c) above, or at the discretion of the Chairman.
k) No member may move more than one amendment to any motion.

5 VOTING

a) Each Full Member present excluding the Chairman shall have one vote.
b) The Chairman shall have a casting vote in the event of a tie.
c) Except for elections, voting shall be by a show of hands unless five Full Members request a ballot.
d) For a motion to succeed, a simple majority shall be required, except that any motion to amend the Constitution, Branch Constitution or Standing Orders shall require a two-thirds majority.

6 ELECTIONS

a) The system of the Single Transferable Vote for the election of members of the OUGS Executive and the OUGS Committee is defined as follows:-

(i) All electors shall mark their ballot papers with their ordered preferences for the allocation of their vote to one or more candidates.
(ii) On the first count candidates shall be allocated the first preference votes on the ballot papers.
(iii) At each count the votes allocated to each remaining candidate shall be counted.
(iv) After each count the candidate allocated the least number of votes shall be eliminated from the election. The votes cast for the eliminated candidate shall be re-allocated to the remaining candidates according to the next preferences marked on the ballot papers.
(v) The counts shall cease when the total votes allocated to one candidate constitute an absolute majority of the total votes cast. The candidate with the absolute majority shall be declared elected.

7 PROCEDURAL MOTIONS

a) Procedural motions shall have a proposer and seconder.
b) Procedural motions shall not be proposed while a member is speaking on a point of order or information or during the taking of a vote.
c) The following Procedural motions may be put to the meeting without discussion:-

- that the motion be now put
- that the motion be not put
- that the motion or amendment be voted on in parts
- that Standing Orders be suspended (which requires a two-thirds majority)
- that the meeting be closed

d) The following Procedural Motions may be put with only one speech for and one against:-

- that the matter lie on the table
- that the matter be referred to the OUGS Executive
- that the matter be referred to the OUGS Committee
- that the matter be referred to a Special Committee for investigation or re-examination
- that the meeting be adjourned temporarily
- a challenge to the Chairman's ruling (which shall require a two-thirds majority)

8 GENERAL RULES

a) No question once decided may be re-opened at the same meeting.
b) Any suspension of the Standing Orders shall only apply for the duration of the matter under discussion.
c) If an amendment is accepted by the proposer of the motion then the motion remains with the proposer. If it is not accepted by the proposer, but is then carried, the amended motion becomes the property of the proposer of the amendment.
d) Amendments tabled second and subsequent to a motion may fall if the first amendment is carried or accepted. The Chairman shall rule on this.
e) Points of information may be raised by any member.
f) Points of order may be raised by any member. They have precedence over all other business except the taking of a vote unless they concern the conduct of the vote. They must be framed as a question to the Chairman and shall be related only to the conduct of the meeting.

ADDENDA 1

1 These Standing Orders shall apply to Branch Meetings of the Open University Geological Society.

2 Branch General Meetings shall be conducted according to Standing Orders for General Meetings, subject to the following amendments:-
i) 1(a) shall be replaced by "*A quorum of 5% of the Branch members or five members, whichever is the greater, shall be required.*"
ii) 2(a) shall be replaced by "*The agenda shall be prepared by the Branch Organiser.*"
iii) 3(a) shall be replaced by "*The Branch Organiser shall take the Chair.*"
iv) 3(b) shall be replaced by "*If the Branch Organiser is absent another member of the Branch Committee shall deputise as Chairman*."
v) 3(e) Delete "*the President or other*" and replace with "*an*"
vi) 5(c) Delete "*Except for elections*"
vii) 5(d) Delete "*Constitution,*" and "*or Standing Orders*"
viii) 7(d) Add "*that the matter be referred to the Branch Committee when the meeting in question is a Branch General Meeting*"

As amended at the AGM of The Society 17 November 2001.